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Oak Ridge National Laboratory REVIEW

• MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY •

ATTRACTING THE Next Generation OF GREAT SCIENTISTS

Wigner FELLOWSHIP PROGRAM

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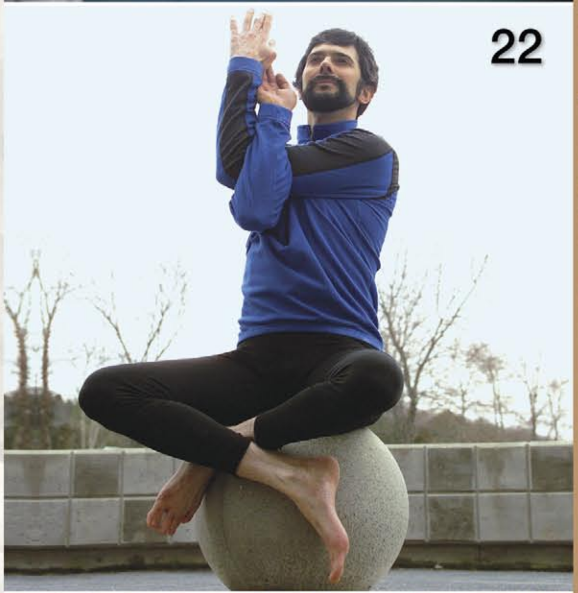
Features



COVER: *Four of ORNL's past and present Wigner fellows—Michael Lance, Maria Varela, Chad Duty, and Adam Rondinone—outside the Laboratory's new conference center.*

THE SEARCH FOR

New Scientific Superstars

After nearly six years, the end is within sight. With approximately $2 billion in new investments from the Department of Energy, the state of Tennessee, and UT-Battelle Development Corporation, Oak Ridge National Laboratory is approaching the final stages of a historic modernization program. New state-of-the-art facilities house growing research programs in life sciences, microscopy, energy, and computation, including the National Leadership Computing Facility. Within twelve months, we will begin operation of the Spallation Neutron Source and the Center for Nanophase Materials Sciences, establishing Oak Ridge as the world's foremost center for the study of neutron sciences. Additional new facilities for biology and neutron sciences are funded and will be soon under construction.

We undertook such a daunting endeavor secure in the knowledge that these marvelous new facilities would be filled with internationally recognized scientists and engineers. Representing every continent and every age group, their collective talent is the source of ORNL's creative energy and the key to the scientific agenda that drives our modernization efforts. One of our challenges in the coming years will be to replace and expand this remarkable talent pool.

Our strategy is multi-faceted. We are seeking, quite simply, scientific superstars, ranging from young postdoctoral researchers to nationally and internationally recognized scientists at the pinnacle of their careers. Our efforts include an unprecedented initiative with the state of Tennessee to provide $20 million for outstanding scientists and engineers who will share distinguished joint positions with ORNL and the University of Tennessee, adding to an excellent cadre of joint faculty with the University.

This issue of the *Review* features another unique part of our recruitment strategy, an expansion of the Eugene P. Wigner Fellowship program that for three decades has served as both a doorway and an "incubator" for some of the Laboratory's most valuable research talent. Some 70 outstanding young scientists have been awarded this prestigious fellowship, which offers a highly competitive salary and benefits. Most significant, two-thirds of the Wigner fellows elect to stay at ORNL beyond their two-year fellowship period. About one-third are still providing outstanding service to ORNL, some at the highest levels of leadership.

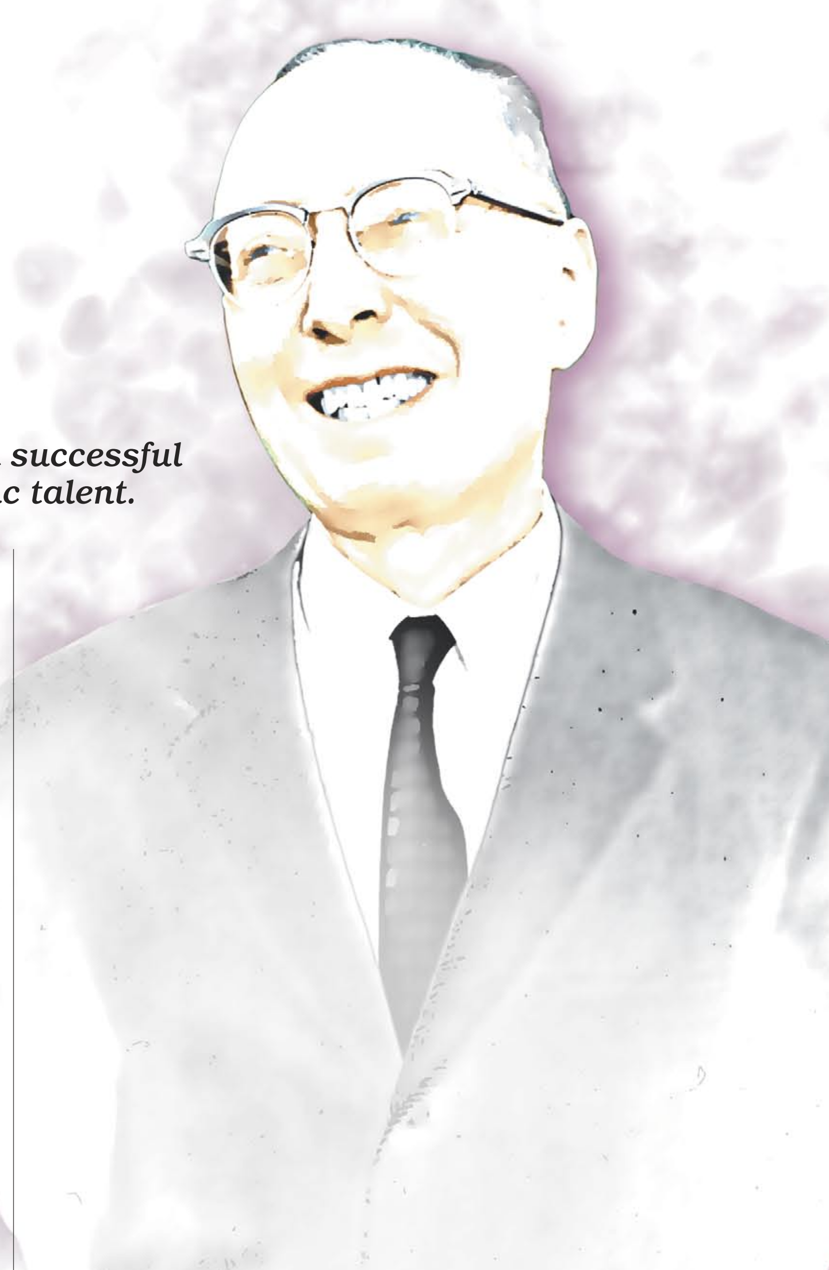
In the past, ORNL has selected and hired two Wigner fellows each year. Looking forward, we will hire eight fellows in 2006, nine in 2007, and 10 in 2008. The articles contained in this issue provide a snapshot of why these outstanding scientists came to Oak Ridge and how over time they shaped our scientific agenda. As I read these articles I came to appreciate how these men and women, more than anything I can imagine, represent the energy and optimism that will define the future of Oak Ridge National Laboratory.

Lee Riedinger, Associate Laboratory Director for University Partnerships at ORNL

Wigner FELLOWSHIP PROGRAM

Filling the Talent Pipeline

The Wigner Fellowship program has been a successful effort to attract and develop young scientific talent.



As head of Ph.D. recruiting at ORNL in 1975, Dan Robbins had a message for Herman Postma, the new ORNL director. Robbins, Chuck Coutant, and other Laboratory scientists had been visiting outstanding research universities to interview the most impressive graduate students in science and engineering. Their challenge was an inability to offer jobs to the most promising students.

Recounts Robbins: "Professors would say, 'This is the best student we've ever seen in metallurgy,' but then we would learn that the Metals and Ceramics Division at ORNL had no money or had not turned in a job description for an open position, so we could not hire this fantastic metallurgist."

Robbins, Coutant, and the other Ph.D. recruiters brainstormed options. What if ORNL could hire the students using a two-year fellowship? The appropriate division could be exposed to the young scientist's energy and imagination. Meanwhile, a fellowship would give the fortunate division time to identify needed funds and create an appropriate research position.

The group urged Robbins to bring the proposal to Postma's attention. Robbins met with the new director and suggested that a two-year fellowship would be a viable way to bring promising young researchers to Oak Ridge before competing institutions snapped them up. Postma offered to fund "a couple of these special postdoc positions out of overhead at a compensation rate comparable to that of an entry-level researcher," Robbins says. "This was a fantastic postdoc rate at the time." He recalls that Postma proposed naming the fellowship in honor of Nobel Laureate Eugene Paul Wigner, the laboratory's former research director and "patron saint." Thus was born the Wigner Fellowship, one of ORNL's most successful recruiting programs.

Coutant was a member of the Wigner Fellowship Selection Committee for 10 years. "It was tough to pick two Wigner fellows each year because we had a stack of applications and they were all top-notch people," he says. "Some of the scientific superstars were attracted by more than just a job. The opportunity to be a "Wigner Fellow" tweaked their imagination. They were drawn to the honor and the prestige in addition to the salary."

Eugene P. Wigner (1902-1995), a Hungarian, was the first director of research and development at Clinton Laboratories (now ORNL), serving in this position from 1946 to 1947. In 1963 Wigner was awarded a Nobel Prize for physics "for his contributions to the theory of the atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles." A nuclear engineer, he designed the water-cooled nuclear reactors at Hanford, Washington, that produced the plutonium used in the second atomic bomb that ended World War II.

"We can trace many of this Laboratory's key strengths today to Eugene Wigner's extraordinary vision," says Lee Riedinger, ORNL's associate laboratory director for university partnerships. "Wigner brought Alvin Weinberg (director of ORNL from 1955 to 1973) to Oak Ridge from Chicago. He also brought Alexander Hollaender to Oak Ridge to establish ORNL's Biology Division. He encouraged Ernest Wollan and Clifford Shull, who won a Nobel Prize for physics in 1994, in their neutron scattering experiments on the Graphite Reactor.

"Wigner established a reactor engineering program that laid the foundation for ORNL's broad expertise in nuclear R&D.

He also established a solid-state research group and a division to investigate the effects of radiation on metals. The extraordinary breadth of Wigner's own scientific work—spanning physics, chemistry, mathematics, nuclear engineering, and civil defense—is reflected in the multidisciplinary nature of this national laboratory."

Wigner was also an educator. He started the reactor training school at ORNL and mentored 40 Ph.D. students, including Frederick Seitz and John Bardeen, who later won a Nobel Prize for physics.

Robbins remembers taking some of the fellows around to meet Wigner when he came to the ORNL in the mid-1970s. "They were mutually delighted," he says.

Oddly, the Wigner Fellows program was not always widely publicized within the Laboratory. "In the 1970s and early 1980s there was no reception for the fellows," Coutant recalls. "The membership of the Wigner Fellowship Selection Committee remained a secret." Today, the Laboratory holds an annual reception for Wigner Fellows, and the members of the selection committee—all ORNL corporate fellows—are publicly identified.

Ben Carreras, current committee chair, characterizes the profile of potential Wigner Fellows. "We seek only the very best researchers. We are conscientious about diversity. We try to identify women and minorities who are first rate in their fields. We interview a large number of foreign nationals. Most candidates are referred to us by members of the ORNL research staff, but some candidates apply after seeing the Wigner Fellowship web site."

Current members of the selection committee are Carreras (chair), Jacob Barhen, Virginia Dale, Vinod Sikka, and Ken Tobin.

"The divisions wanting a Wigner fellow must be committed to recruiting very bright people, providing mentoring, teaching proposal writing, providing resources and support, and finding a position for the fellow in two years," Carreras says.

"The committee does not interview the candidates. Members do, however, review their applications, papers, patents, thesis drafts, and references. Qualified candidates are required to give a one-hour seminar at ORNL. That's how we judge their scope of knowledge, creativity, critical thinking skills, communication skills, and ability to answer questions on their feet."

Carreras emphasizes that the program's value is evident in the number of fellows who remain at ORNL. "We retain two-thirds of our Wigner Fellows after their fellowship tenure expires. Some leave because they get exceptional offers from universities to be assistant professors, indicating that our program recruits top-notch people."

In an environment of increasing competition for top scientific talent, the Wigner Fellowship program is among the nation's most attractive avenues for young researchers to begin their careers. For ORNL, expanding upon the program's success will be a vital part of the Laboratory's commitment to filling the talent pipeline in the years ahead. Ⓡ

STILL MAKING A MARK

Two former Wigner Fellows have achieved distinction in their respective fields after leaving ORNL. One is A. Baha Balantekin, who came to Oak Ridge as a Wigner Fellow in 1984-86 and now, somewhat ironically, holds the Wigner Chair at the University of Wisconsin, where the Nobel Laureate Eugene P. Wigner was once a professor.

A second is Mike Ramsey, who came to ORNL in 1979 as a Wigner Fellow. He became an ORNL corporate fellow in 1997 after inventing the "lab on a chip" and pioneering the new field of microfluidics. Ramsey left ORNL in 2004 to become the Minnie N. Goldby Distinguished Professor of Chemistry with positions in the Department of Chemistry, the Institute for Advanced Materials, Nanoscience and Technology, and the Carolina Center for Genome Sciences at the University of North Carolina at Chapel Hill.

Balantekin, a native of Turkey, earned his Ph.D. degree in physics from Yale University. At ORNL he worked on understanding anomalies observed in heavy-ion collisions. After leaving Oak Ridge he made important contributions in mathematical physics and neutrino physics. "I am now involved in efforts to build an underground laboratory where neutrino physics experiments will be carried out," he says.

Ramsey's lab on a chip was honored by R&D magazine as one of the 40 top innovations since 1963. The technology also was recognized by the Department of Energy as among the top 23 developed by agency funding. Two companies are selling devices based on his invention that they hope will lead to discoveries of better therapeutic drugs.

"ORNL provides a good balance between the freedom to do academic research and opportunities to work on projects that are applied, relevant, and useful to society."

Ryan Bennink, a current Wigner fellow, is a proficient musician.

The Critical Difference

Wigner fellows say a unique balance of freedom and opportunity brought them to Oak Ridge.

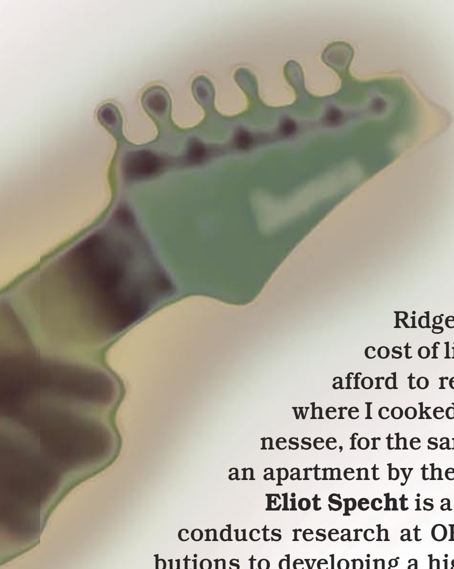
The *ORNL Review* asked two important questions of some current and former Wigner Fellows. The questions were: "What do you think of the Wigner Fellowship program?" and "What is your impression of ORNL as a place to do research?" The answers are revealing.

Ryan Bennink, a current Wigner fellow, is helping ORNL build its quantum optics program. "I think the Wigner Fellowship program is a great deal for me," he says. "I'm happy to be here. My fellowship gives me the freedom to research the ideas that I'm really interested in. At the same time, the program gives me time to establish myself.

"I like ORNL as a place to do research. The environment is one that provides some really exciting work. ORNL also provides a good balance between the freedom to do academic research and opportunities to work on projects that are applied, relevant, and useful to society. I feel fortunate to be in this position where I am getting paid to think about problems that are interesting to me."

"An added bonus is a nice, new building with beautiful, clean laboratories. The people around here are really friendly. Oak Ridge is a nice place to be."

Maria Varela, a native of Madrid, Spain, studies materials using ORNL's electron microscope that currently holds a world record for atom-scale resolution. She is glad to have accepted the Wigner Fellowship that she won, much to her surprise.



"Oak Ridge is the place to be," she says. "Scientifically, because of our new facilities, many of our new hires are heavyweights. Professionally, it's really exciting to be here right now."

Varela is glad she chose Oak Ridge for another reason—the low cost of living. "In Berkeley, I could only afford to rent a crappy studio apartment where I cooked by the toilet bowl. In East Tennessee, for the same amount of money, I can rent an apartment by the lake and have a boat."

Eliot Specht is a former Wigner Fellow who still conducts research at ORNL. He has made key contributions to developing a high-temperature superconducting tape with a strong potential of being commercialized. Specht attributes much of his success at ORNL to the Wigner Fellowship Program. "The Wigner Fellowship was critical to my decision to come to ORNL," he says. "I had received a competing offer for a staff position. I would not have come to ORNL if I had been offered only a postdoctoral position."

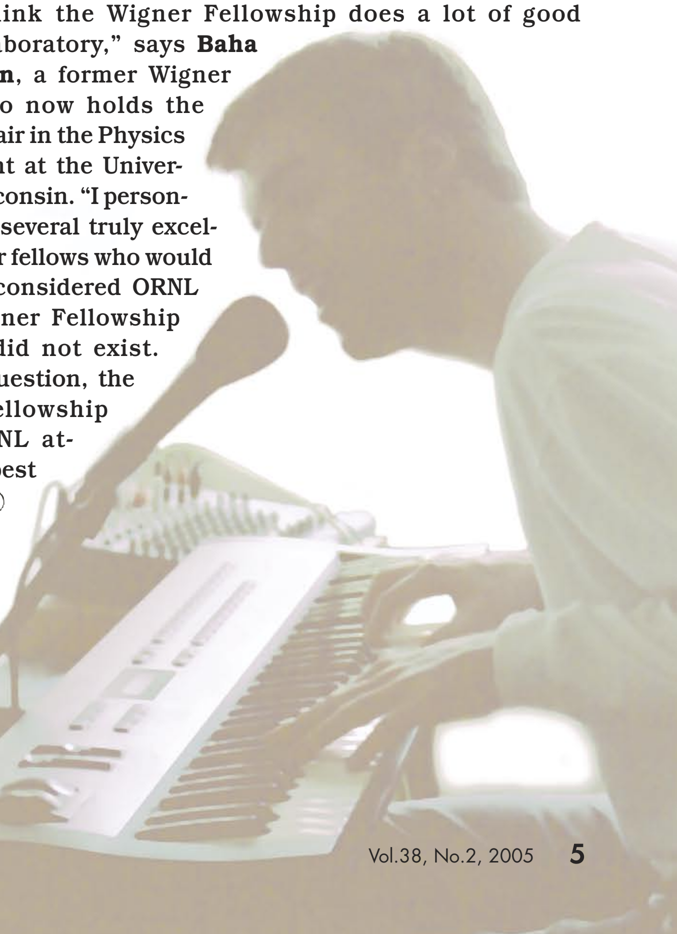
Nevertheless, Specht is glad that ORNL became his long-term employer. "Oak Ridge maintains some of the best synchrotron radiation facilities in the world," he says. "The Laboratory gives its staff the freedom to develop and exploit these facilities. Quite simply, this is a great place to work."

Ingrid Busch, a former Wigner fellow at the National Transportation Research Center, agrees. "The facilities here are wonderful and constantly improving," she says. "I am impressed by the caliber of my co-workers and their dedication to doing important work and doing it well." Busch has developed routing and scheduling algorithms for use by the U.S. Air Force's Air Mobility Command, which schedules airlifts to deploy troops and equipment in response to contingencies and disasters.

"I certainly believe the Wigner Fellowship program is a fantastic way of attracting great people to ORNL," says **Mark Lumsden**, a former Wigner fellow with ORNL's Center for Neutron Scattering. "The prestige, salary enhancements, and high probability of future employment provided by the program certainly make ORNL more appealing than many other institutions to those considering their options after graduate school."

Steve Zinkle, a former Wigner fellow who was recently named an ORNL corporate fellow, says: "I liked the Wigner Fellowship because I was given flexibility and free reign to pursue my scientific interests. In return, I felt like I had additional expectations to perform. I was motivated to work above and beyond my natural abilities. If you recruit the best people, they will try to exceed expectations. They will grow to be the future leaders of the Laboratory."

"I think the Wigner Fellowship does a lot of good for the Laboratory," says **Baha Balantekin**, a former Wigner fellow who now holds the Wigner Chair in the Physics Department at the University of Wisconsin. "I personally know several truly excellent Wigner fellows who would not have considered ORNL if the Wigner Fellowship program did not exist. Without question, the Wigner Fellowship helps ORNL attract the best people." ®



A Winning Couple

The D'Ursos have garnered numerous awards, including Wigner Fellowships.

Brian and Vicky D'Urso are the first married couple to come to ORNL as Wigner Fellows. Neither was recruited by the Laboratory. As simple as it sounds, the graduates of the California Institute of Technology found information about ORNL and the Wigner Fellowship program on the Internet.

As a doctoral student in atomic physics at Harvard University, Brian received the Hertz Foundation Fellowship for exceptional creativity and outstanding potential in research. "The Hertz Foundation encouraged us to look at the Department of Energy's national labs as a place to go after graduate school," Brian says.

"The Hertz Foundation places a value on giving back to the nation, so working at a national lab would fulfill that duty," says Vicky, who has a Ph.D. degree in economics from the Massachusetts Institute of Technology. "I learned that economists do research at ORNL, so there was an opportunity for me to come to Tennessee."

Brian says he knew little about ORNL until he read about the Laboratory online. The couple had interviewed at Caltech and looked at Lawrence Livermore National Laboratory, but the D'Ursos decided to give Oak Ridge a chance. "Once we came here and looked at ORNL and the area and met everybody, we fell in love with the place. It's less congested here, and we love our house in Clinton."

Brian enjoys gardening. Vicky is a potter. Her pots are displayed in their home and in their ORNL offices and are sold at Appalachian Arts in Clinton, where she sometimes teaches pottery.

"I make functional stoneware out of the elements," Vicky says. "Pottery is a great way to express my artistic side. My research in economics is analytical, and my pottery provides a final product that's tangible."

Magic Material

At ORNL, Brian has made something functional—out of the elements, presumably. But he cannot discuss his research other than to say his work involves an exciting nanostructured material that may have national security applications. He hopes to describe this "magic" material in a seminal paper in either *Nature* or *Science* magazine later this year.

Since June 2003, Brian has worked as a Wigner Fellow with the Advanced Lasers, Optics, and Diagnostics Technology Group, led by Steve McNeany. The group is in ORNL's Engineering Science and Technology Division, which plans to hire Brian as a staff member when his Wigner Fellowship expires in June 2005.

A native of Portsmouth, Rhode Island, and the son of an electrical engineer, Brian remembers "tinkering with his grandfather's junk machines" as a child. He recalls taking apart a clock and putting it back together in working order.

One of Brian's favorite projects at Caltech was nanofabrication of photonic crystal structures after he modeled them on a computer. He learned a couple of techniques for etching holes 500 nanometers apart in a specific pattern on a thin slab of a semi-conducting, light-emitting material. When laser light was shone on the crystal structure, light was generated in the slab and then reflected, turning the slab into a two-dimensional photonic bandgap crystal mirror that might be made into an optical switch. For this research, Brian received the Apker Award of the American Physical Society in 1998 for undergraduate achievement in physics.

At Caltech Brian met Victoria Tanusheva, a native of Bulgaria who moved with her family to California when she was 15 so that her father, an applied mathematician, and mother, a chemist and librarian, could find a better life. Vicky and her family lived in Northridge, California, and experienced the January 17, 1994, earthquake. "There were stacks of papers and books under our refrigerator, and our kitchen was two feet deep in dishes and broken eggs," she recalls. "But nobody got hurt."

Vicky and Brian share a love for physics. She majored in math but took a lot of physics courses to prepare for a career. "Where I grew up, everyone worked and there were no stay-at-home moms," she says. For two years Vicky worked for a professor of physics doing research on how snowflakes grow.

"We put water vapor in a cloud chamber that slowly moved down and cooled forming snowflakes, which we then photographed and studied," Vicky says. "We wrote a paper published in

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Physical Review Letters A about how the dendrites—the jagged ends of snowflakes—grow and develop. We confirmed that no two snowflakes are alike, but they can be made to be alike if the temperature profile is the same for each as they swirl in the air.

"The Caltech people concluded my research was original and awarded me the Richard Feynman Prize in Theoretical Physics. It was a great honor."

After graduating from Caltech, Brian and Vicky got married. They immediately headed for graduate school in Cambridge, Massachusetts.

For his Ph.D. thesis at Harvard, Brian moved from Caltech's curiosity-driven research to a more focused project of measuring precisely the magnetic moment of a single electron trapped in an extreme vacuum better than 10^{-16} Torr. The electron was cooled to a temperature of about 50 milliKelvin.

"We were able to trap the electron there for about six months," Brian says. He developed cooling and detection techniques in order to measure its "g value." Out of Brian's thesis came two papers for *Physical Review Letters.*

House on a Hill

For her doctoral thesis at MIT, Vicky studied how use of the Internet's search capability can affect a person's final selection of a house or apartment.

"I found that people using the Internet take longer to find the house or apartment they want," she says. "You become pickier because you have so much more information about what's available, so you drive around to look at all of the choices. You become more educated about what you want."

Did Vicky and Brian find their house in Clinton using the Internet? "We did look on the Internet at a few houses," she says. "Then our real estate agent showed us a house on a hill that we fell in love with and decided to buy. Later we found it again on the Internet and realized it was the house we had rejected right away because the picture looked so terrible."

Before coming to ORNL in 2003 as a Wigner Fellow in a group led by Amy Wolfe in ORNL's Environmental Sciences Division, Vicky completed a postdoctoral research program at the Sloan School of Management. There she worked on an interdisciplinary team investigating the impact of technology and information on organizational performance.

At ORNL Vicky wrote a proposal that received DOE funding. The funded project, for which she is the principal investigator, is a market analysis by researchers at three national labs. She is studying how information presented online about different energy technologies, such as appliances and hybrid vehicles, plays out in the marketplace. She is attempting to determine how consumers respond to this information and how the information affects their purchasing decisions.

Vicky uses computer simulation to develop theories about how people become aware of products and learn more about them from web sites, commercials, and other people. "The missing link is how to get energy-efficient technologies out to the consumer," she says. "For example, one ORNL heat pump would sell better if it were less top heavy and easier to install. An overarching theme in my work is how to make a connection between society and technology."

Another project for which she obtained program development funds from Dave Hill's Energy and Engineering Sciences Directorate is a study of how researchers' creativity is affected by the organization and dynamics of Hill's directorate.

"We've had to define creativity," Vicky says. "Creativity lies in the intersection between originality and success, and measures of success include researchers' awards, publications, and status in professional organizations."

Creativity also lies in the minds of Wigner fellows like Brian and Vicky. Great talent loves company. Ⓡ

Brian D'Urso enjoys gardening at home.

The Best of Both Worlds

Three Wigner fellows divide their time between the laboratory and the classroom.

As a young researcher, Sean Agnew gained a competitive edge when he was named a Wigner fellow in 1999. Three years ago, after he had left ORNL to serve as an assistant professor at the University of Virginia (UVa), he retained his competitive edge by becoming the first former ORNL employee to win a joint faculty appointment at ORNL and an out-of-state university.

UVa is one of UT-Battelle's core universities.* Agnew teaches in UVa's Materials Science and Engineering Department, serves as the thesis advisor for five graduate students, and conducts research on magnesium alloys in collaboration with ORNL researchers Craig Blue, Joe Horton, and Phil Sklad.

Agnew began working on magnesium alloys when he was encouraged to start a new program by his group leader in ORNL's Metals and Ceramics Division as part of his Wigner Fellowship program. "It was a dealmaker for me," Agnew says, noting that he passed up offers from a corporation and other national labs. "The fellowship's good salary, prestige, and freedom to work on what interests me were definitely incentives for me to come to Oak Ridge."

As a Wigner fellow, Agnew wrote a successful seed money proposal that started a growing program at ORNL to study the mechanical behavior of magnesium alloys. These alloys, which are approximately 4 times lighter than steel, are of interest to DOE and the automotive industry because they may be useful as structural materials for cars and trucks to help reduce their use of fuel.

DOE later funded Agnew to apply a technique he had studied for his Ph.D. thesis at Northwestern University—severe plastic deformation—to the processing of wrought magnesium. Agnew and his collaborators continue developing new magnesium alloys and fabrication processes so that wrought magnesium (rather than cast magnesium) can be used in vehicles more easily and cheaply. Part of that work has involved fundamental scientific studies of deformation mechanisms such as "mechanical twinning," which allows a material to deform by producing a structure in which the crystals on either side of the "twin" boundary resemble a mirror image of each other.

"Young faculty members know it's a real struggle to get funding for a new research program," Agnew says. "I appreciate my joint faculty appointment and the Wigner Fellowship because they have smoothed the way for me to establish my research program."

Agnew comes to ORNL periodically for review meetings and to make use of the Laboratory's special research capabilities—things that UVa cannot easily afford, such as the ability to make and process alloys. "This summer, a student and I will come to ORNL for an extended stay to get some research done," he says. "I plan to come to ORNL in a few years to conduct research using neutron scattering at the Spallation Neutron Source."

Agnew teaches one class a semester, among which are "Introduction to Materials Science," "Physical Metallurgy," and "Mechanical Behavior of Materials." Three of his five graduate students have already obtained M.S. degrees and three are currently pursuing Ph.D. degrees.

Dividing His Time

Thomas Papenbrock, a native of Germany, has a joint faculty appointment with the University of Tennessee and the Laboratory. He spends two to three days a week at UT and the remainder at ORNL.

He received a doctoral degree in physics from the University of Heidelberg in Germany. He completed a three-year postdoctoral assignment at the Institute for Nuclear Theory at the University of Washington in Seattle. In late 2000, he became a Wigner fellow in ORNL's Physics Division, where he investigated nuclei and other quantum many-body systems.

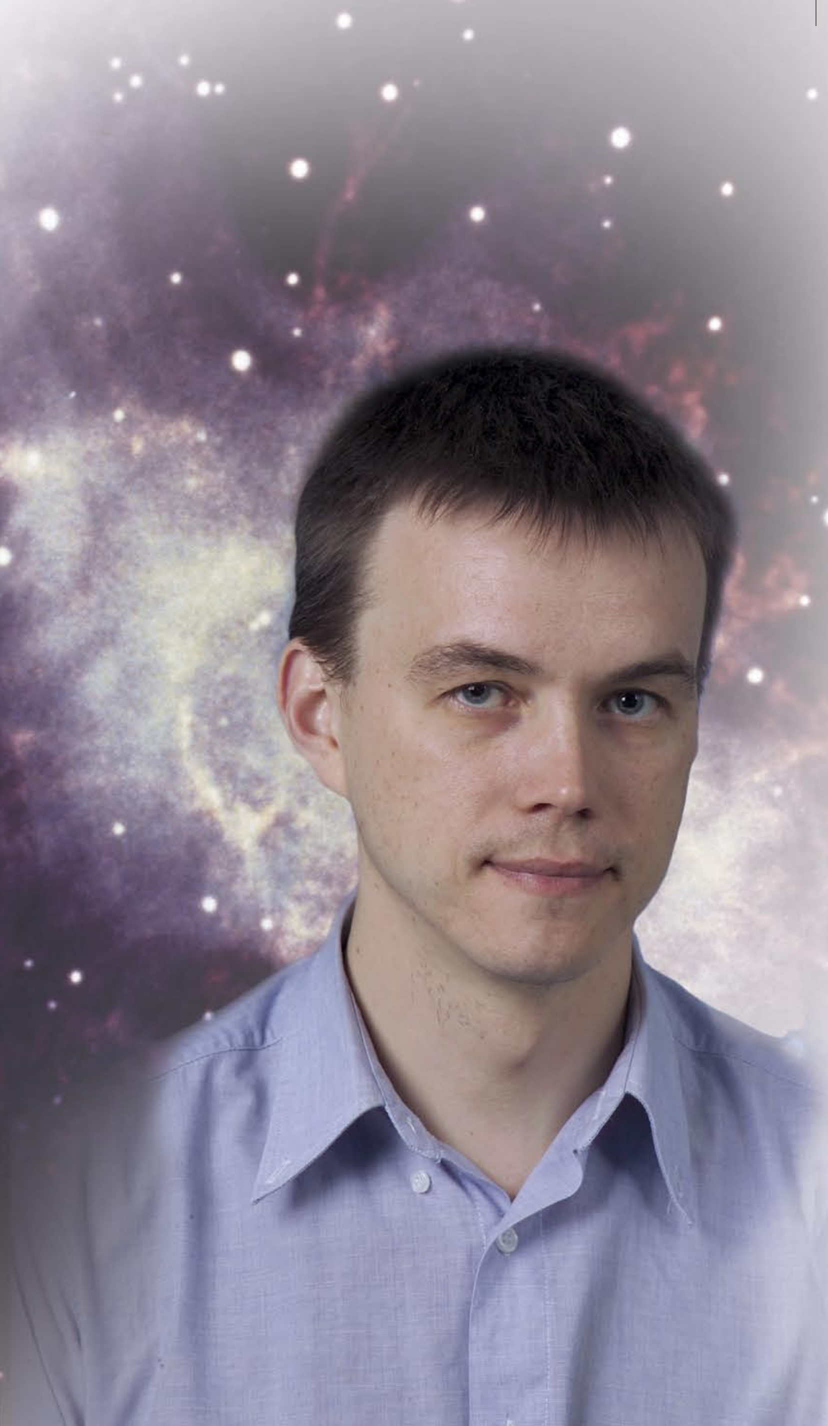
In August 2004 he was appointed a joint faculty member for UT and ORNL. "Now I am based at UT where I co-taught the nuclear physics course last fall," he says. "I apply quantum many-body theory to nuclei, to systems of ultra-cold, trapped atoms, and to spin chains."

Roberyt Grzywacz is a star physicist at ORNL who teaches astromony at UT.

Using the SGI Altix supercomputer and data acquired from experiments at the Holifield Radioactive Ion Beam Facility (HRIBF) at ORNL, Papenbrock aims to achieve a better understanding of the "strong force" between protons and neutrons that make up short-lived, unstable, neutron-rich nuclei.

"The strong force between any pair of nucleons in these nuclei is not simple to measure or predict," Papenbrock says. "By doing calculations and comparing the answers with the results of nuclear physics experiments at HRIBF, we can determine new aspects of the strong force that holds the nucleus together.

"When physicists 'ping' a nucleus with a probe, the nucleus becomes excited and might, for instance, vibrate or rotate. We can infer whether the nucleus is spherical or deformed by measuring its mass and analyzing its excitations. We can, for instance, determine whether neutron-rich nuclei have a neutron skin or a neutron halo."



The understanding of the strong force, and how it determines the structure of nuclei, is far from complete. The importance of three-body forces for the structure of light nuclei has only recently been established. Papenbrock is now extending this theoretical treatment toward heavier nuclei. He is also developing new approximation methods that make theoretical calculations addressing the nuclear many-body problem more feasible and less expensive.

East European in East Tennessee

Robert Grzywacz works in ORNL's Physics Division and teaches astronomy as a faculty member at UT. He emerged as a scientific superstar in nuclear physics 10 years ago while working on his thesis at Warsaw University in Poland. In 1995 he was awarded a prestigious scholarship for young researchers by the Foundation for Polish Science. The award recognized his development of a method for discovering metastable states in exotic nuclei that decay in one-millionth of a second after being produced in heavy-ion fragmentation reactions.

"I discovered a neat method of plotting the data to identify and quantify the excited isomers that decay to the ground state by emitting gamma rays," he says. "This highly sensitive method finds short-lived isotopes in metastable states that are produced at very low rates after a beam of accelerated ions collides with a target."

The Warsaw group was the second to produce and identify the doubly magic tin-100 isotope. "We produced 22 atoms of this isotope while doing research in France." Grzywacz was recruited from Poland to continue his nuclear physics studies in the United States, first as a postdoctoral researcher at the University of Tennessee and later as a Wigner Fellow at HRIBF. "I was recruited by Krzysztof Rykaczewski, my first thesis advisor at Warsaw University, who later joined the ORNL staff," Grzywacz says. "He helped me get a postdoctoral assignment at UT from 1998 through 2000 and a Wigner Fellowship later, allowing me to do nuclear physics research at ORNL.

"We developed new methods of detecting short-lived proton emitters at HRIBF using next-generation, digital-signal processing electronics to acquire data in real time," he says. "The electronics, which can be easily modified by only changing the codes, enable detection of tiny signals—such as the emission of protons or electrons—almost instantly after the radioactive ion arrives at the detector."

After Grzywacz became assistant professor of physics at Warsaw University, he conducted research at Germany's GSI laboratory. "We discovered a new type of radioactivity," he says. "We found a nucleus that simultaneously emits two protons from the ground state. We used the electronics and experience gained at ORNL during our proton radioactivity experiments."

This advanced electronics will likely be used to help determine the fundamental properties of the neutron at the Spallation Neutron Source at ORNL. Ⓡ

** UT-Battelle's core university partners are Duke, Florida State, Georgia Tech, North Carolina State, Virginia, Virginia Tech, and Vanderbilt.*

Mentors and Inventors

Four outstanding researchers enjoy an unusual mentor-student relationship.

Steve Zinkle and Chad Duty

Steve Zinkle is a former Wigner fellow who became a corporate fellow, Oak Ridge National Laboratory's highest scientific distinction. Zinkle also is a former Wigner fellow at ORNL who is mentoring a current Wigner fellow, Chad Duty. Duty is working on a space reactor materials project. Nancy Dudney, a former Wigner fellow, was a mentor to a Wigner fellow and is still a mentor to former Wigner fellow Young-Il Jang. Together they are working on a project related to improving batteries for the next-generation hybrid vehicles. Their stories are yet another chapter of the Wigner fellowship program at ORNL.

Surprising Success

Some people may be surprised that Steve Zinkle, son of a Wisconsin farmer and elementary schoolteacher, grew up to be a successful scientist. "Science was my worst subject as a kid, possibly because I had to memorize a bunch of facts," he says. "I hated arithmetic, especially adding large numbers." But Zinkle won the eighth-grade science award and his aptitude scores led his high school guidance counselor to tell him, "You should go into engineering."

Between 1980 and 1985, Zinkle received his B.S. and Ph.D. degrees in nuclear engineering and his M.S. degree in materials science at the University of Wisconsin at Madison. For his thesis, he studied the effects of ion irradiation on the microstructure and properties of several copper alloys.

As a graduate student, Zinkle spent two summers doing research at Lawrence Livermore National Laboratory. "I would have taken a position at Livermore," he says. "if I hadn't been offered a Wigner Fellowship that resulted from an on-campus interview with an Oak Ridge recruiter who knew one of my Wisconsin professors."

"I would have taken a position at Livermore if I hadn't been offered a Wigner Fellowship. . ."

Most of Zinkle's career has been spent in ORNL's Metals and Ceramics Division, interacting with the Laboratory's strong research staff in radiation effects in materials and using world-class tools such as the High Flux Isotope Reactor (HFIR) and analytical electron microscopes. Zinkle also worked in Germany, Denmark, and Russia. He has managed several large research programs while conducting his own research, which has had a major impact on materials science.

For example, published results in the literature concerning ceramic samples exposed to neutrons in different fission reactors provided conflicting information. "I was able to sort out what was going on," he says. "I explained how ionizing radiation affects the ways a material's defects migrate and recombine." For this work, Zinkle received a Best Paper award from the American Ceramic Society.

Zinkle is now leader of the fast-growing Nuclear Materials Science and Technology Group. He is involved in materials R&D for the fusion plasma containment structures of the planned

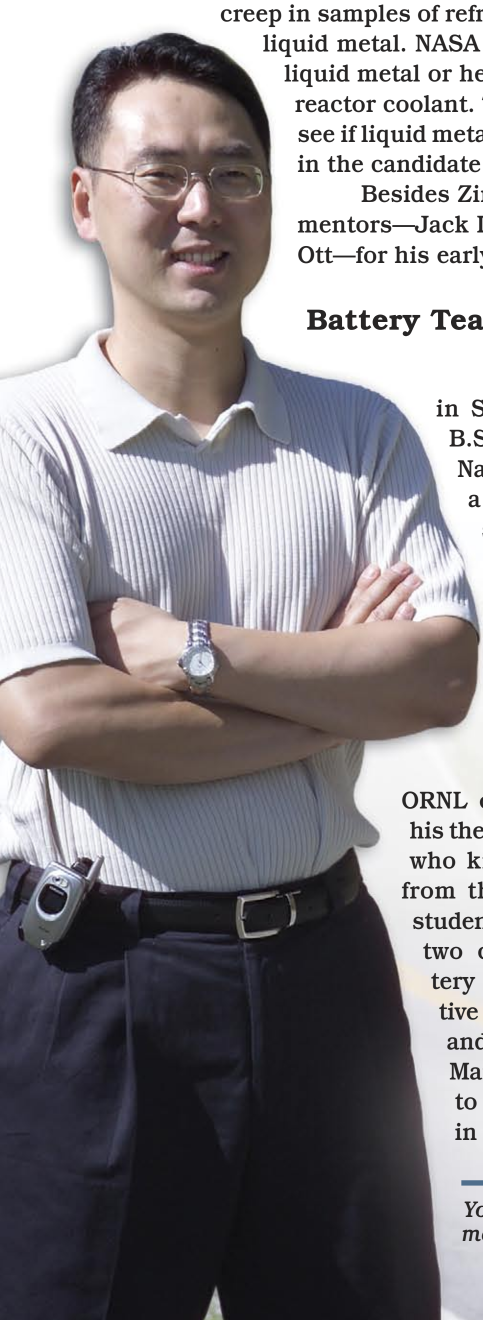
International Thermonuclear Experimental Reactor (ITER). "My main research interests," he says, "are understanding how the microstructures of materials control their bulk properties, both at high temperatures and under neutron irradiation conditions."

Chad Duty is the first Wigner Fellow that Zinkle has mentored. "We have thrown him into a new area and he adapted very well, just as you'd expect of someone with his capabilities," Zinkle says. "Our group has a rapidly growing program on materials for reactors being developed for NASA's spacecraft probes that will explore planets, such as Jupiter, and their moons.

"Chad is one of the key members of the team that will help determine which refractory materials will be at the heart of the space reactor system. The selected materials must last 15 years, with very high reliability, at a temperature near 1000°C. NASA needs more data to determine which of the candidate alloys is least likely to soften over 15 years."

Duty is a native of Virginia who earned a Ph.D. in mechanical engineering from Georgia Tech, where he co-invented a rapid prototyping method using laser chemical vapor deposition. He is currently leading an effort to measure high-temperature thermal creep in samples of refractory materials exposed to liquid metal. NASA is trying to decide whether liquid metal or helium should be used as the reactor coolant. Tests must be conducted to see if liquid metal triggers any showstoppers in the candidate materials.

Besides Zinkle, Duty credits his other mentors—Jack Lackey, Craig Blue, and Ron Ott—for his early career successes.



Battery Team

Young-Il Jang, who grew up in Seoul, Korea, obtained his B.S. and M.S. degrees at Seoul National University. He earned a Ph.D. degree in materials science and engineering in 1999 at the Massachusetts Institute of Technology. For his doctoral thesis, Jang co-invented and studied oxide cathode materials for rechargeable lithium batteries.

Jang interviewed at ORNL on the recommendation of his thesis advisor, Yet Ming Chiang, who knew ORNL's Nancy Dudney from their days as MIT graduate students. After leaving Boston, the two continued to interact at battery conferences. Dudney, a native of Pittsburgh, Pennsylvania, and a graduate of William and Mary College in Virginia, came to ORNL's Solid State Division in 1979 as a Wigner fellow. A daughter of a Ph.D. solid-state chemist at Westinghouse Electric Corporation, Dudney is now leader of the Thin-Film Ceramic Group in ORNL's Condensed Matter Sciences Division.

In the late 1980s Dudney teamed with John Bates on a winning seed money proposal to construct a thin-film lithium battery. A prototype of the battery built at ORNL received considerable media attention. "It was a fun project," Dudney says. Bates left ORNL to start a company to commercialize the tiny battery. Other companies since have called Dudney asking her advice about marketing the technology.

"When Young-Il came here for an interview, it quickly became apparent that he had the right qualities to compete for a Wigner Fellowship," Dudney says. "The fellowship was an obvious thing to pursue."

Starting as a Wigner fellow in 2000, Jang worked with Dudney on the fundamental materials problems related to developing batteries for hybrid gasoline-electric cars. A Department of Energy goal is a battery that can store considerable electrical energy in a small, light package. Lithium is a choice material for at least one of the battery's electrodes because of the lightweight material's high specific energy.

One important issue relative to lithium ion batteries is the diffusion of lithium ions in electrode and electrolyte materials. While a Wigner fellow, Jang studied diffusion phenomena in lithium cobalt oxide, which is the most widely used commercial cathode material, as well as the exemplar of layered intercalation oxides.

"I recognized the thin-film battery provided the ideal geometry to study diffusion," says Jang. "Geometrical uncertainties plagued previous studies, and the literature values for lithium diffusivity varied by six orders of magnitude."

"The work will stand as the authoritative reference on transport properties in this compound," notes MIT's Chiang.

Dudney and Jang have started research on lithium-sulfur batteries for hybrid vehicles. Their work is funded by DOE's Office of FreedomCAR and Vehicle Technologies in the Office of Energy Efficiency and Renewable Energy.

"DOE wants us to look at what's next in new materials for hybrid cars," Dudney says. "Like lithium, sulfur is lightweight, and both have a very high energy density. Each would be an electrode, and the electrolyte would likely be organic liquids. One problem that must be addressed is that these electrode materials may eventually lose their integrity."

Most of today's hybrid cars have nickel–metal hydride batteries. Nickel costs 200 times as much as sulfur. "In theory, a lithium-sulfur battery could provide the same runtime with only one-tenth the weight of today's hybrid car batteries," says Jang.

Jang considers Dudney a "great" mentor. "She makes herself available whenever I need her advice and encourages me to explore my own research interests." Ⓡ

Young-Il Jang studies battery materials for hybrid cars.

Coming Home

Two Tennesseans go to graduate school in New England, but Wigner fellowships bring them home.

As a teenager in Nashville, Tennessee, Dan Bardayan watched the clouds and pondered weather data. But during his undergraduate years as a physics major at Tennessee Tech University in Cookeville, he became less interested in becoming a meteorologist and more excited about pursuing graduate degrees in nuclear physics. In his senior year he looked beyond the clouds to the radioisotopes that make up cosmic rays. By the time he graduated, his name had appeared in *Physical Review C* on his first scientific paper, which he co-authored with his thesis adviser, a Yale University graduate.

"Using gamma-ray detectors, we studied rare beta decays in certain radioisotopes with long half lives that exist in cosmic rays," Bardayan says. "By measuring the rare decay lifetimes of these isotopes and determining the ratios of these isotopes in cosmic rays, we can predict how many millions of years ago these isotopes were generated, in effect making them cosmic ray chronometers."

Thanks partly to this paper, great grades and standardized test scores, and his adviser's influence, Bardayan was able to study nuclear physics at Yale, where he received two master's degrees and a Ph.D. degree by 1999.

To earn his doctoral degree, Bardayan returned to Tennessee and spent three years conducting nuclear astrophysics research at ORNL's Holifield Radioactive Ion Beam Facility (HRIBF). He conducted a successful thesis experiment with radioactive ion beams to get information that scientists had tried unsuccessfully to obtain with stable beams for 30 years. On the basis of that work, Bardayan received the 2001 Dissertation in Nuclear Physics Award from the American Physical Society, "for the best dissertation in nuclear physics over a two-year period by a graduate student at a North American university." Bardayan also received the 2000 UT-Battelle Author of the Year award for his scientific paper on this experiment, published in the July 1999 issue of *Physical Review Letters*.

Back to Tennessee

Bardayan came to Oak Ridge for his thesis research because his Yale thesis advisor and professor of nuclear astrophysics happened also to be the thesis adviser of ORNL physicist Michael Smith. When Smith started to set up a nuclear astrophysics program at HRIBF, this same Yale professor promised him a graduate student. That graduate student ended up being Bardayan. "As a native Tennessean, I was interested in doing research in Oak Ridge," he says.

The goal of Bardayan and Smith's experiment was to search for the theoretically predicted quantum state of neon-18 nuclei, which could be produced only when radioactive fluorine-17 nuclei fuse with hydrogen. "It was only when ORNL researchers were able to develop

Dan Bardayan performs experiments at the Holifield Radioactive Ion Beam Facility.

a radioactive ion beam of fluorine-17 that we were able to find the reported quantum state," Bardayan says.

"Our team performed experiments to determine nuclear reactions that produce fluorine-18, and then we conducted experiments to identify the nuclear reactions that destroy fluorine-18." Bardayan says. "Our findings indicate that more net fluorine-18 is produced in novas than scientists previously believed. Novas are explosions in stars; our galaxy has about 30 of these a year. Fluorine-18 is abundant and has a long half-life. Gamma rays from fluorine-18 in space can be detected by observatories in satellite telescopes. Because we cannot send a space probe to a nova, we need HRIBF to help us determine the nuclear reactions that produce and destroy fluorine-18. In the next 10 to 15 years, a satellite telescope may be pointed in the right direction during a nova explosion and verify that fluorine-18 is there."

To perform these experiments, Bardayan had to find ways to come back to Oak Ridge. So, for four years he conducted research at ORNL as a postdoctoral scientist with the University of North Carolina and then as a Wigner Fellow. During that time, he developed SIDAR, a silicon detector array that detects alpha particles and other light ions emitted when radioactive ion beams collide with targets at HRIBF.

Bardayan now is helping with the development of the next-generation version of SIDAR, which will detect 10 times more particles for the same number of beam ions. He found another route to ORNL; he was hired in 2003 as a staff member in the Physics Division, whose director is Glenn Young, also a former Wigner fellow and a Tennessee native.

Meeting Wigner

Glenn Young grew up in Kingsport, surrounded by scientists and engineers both at home and in his neighborhood. His father has a Ph.D. degree in physical chemistry and his mother earned an M.S. degree in biology. Young obtained a bachelor's degree in physics from the University of Tennessee and a doctoral degree in nuclear physics from the Massachusetts Institute of Technology in 1978.

Young was not sure what he would do after he got his Ph.D. degree. While walking through the MIT biology building on his way to the elevator to go home, he happened to see a poster advertising the Wigner Fellowship program in Oak Ridge.

"I couldn't tell whether a nuclear physicist doing basic research qualified," he says. "I happened to see Lee Riedinger (now an ORNL associate lab director) in Rochester, New York, that fall at a conference. He invited me to come to Oak Ridge over winter break to give a seminar, which I did. Ed Gross sent me a job application, and John Pinajian called and offered me a job at ORNL.

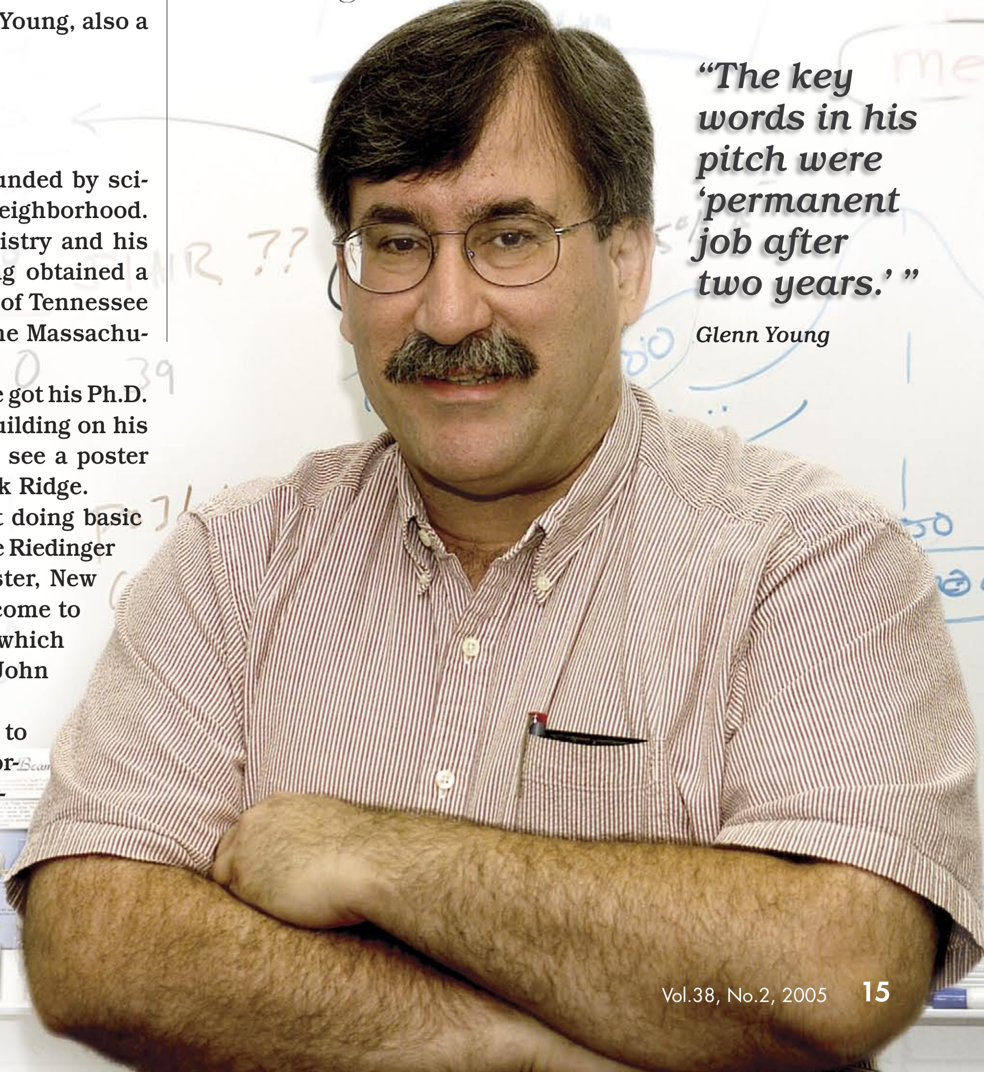
"My MIT professors found out and started to press me about staying there to take an instructorship. However, I'd seen young men take instructorships and not make the next step onto the faculty, so I was skeptical. A week later, John called back and offered me a Wigner Fellowship. The key words in his pitch were 'permanent job after two years.' That was unheard of in 1978, so I said yes."

As one of the Laboratory's early Wigner fellows, Young had the privilege of discussing his research with Eugene Wigner. "I described my research to Professor Wigner concerning a transition from one type of reaction to another, as indicated by neutron and alpha particle emission following inelastic collisions of light nuclei. He poked and prodded. He characterized something I said as 'very interesting.' That comment made me happy, but 20 years later I was told that that was his polite way of saying he didn't believe a word you were saying. He was right, but it took us two years to work this out experimentally."

Young describes the latter part of his research career as a rather long quest for a state of deconfined quarks and gluons, called the quark-gluon plasma, believed by scientists to have been present in the first 10 microseconds after the universe's birth. With imagery unique to Tennessee, he says, "It's like letting the innards of a proton or neutron out to roam freely, quite in contrast to their normal confined state."

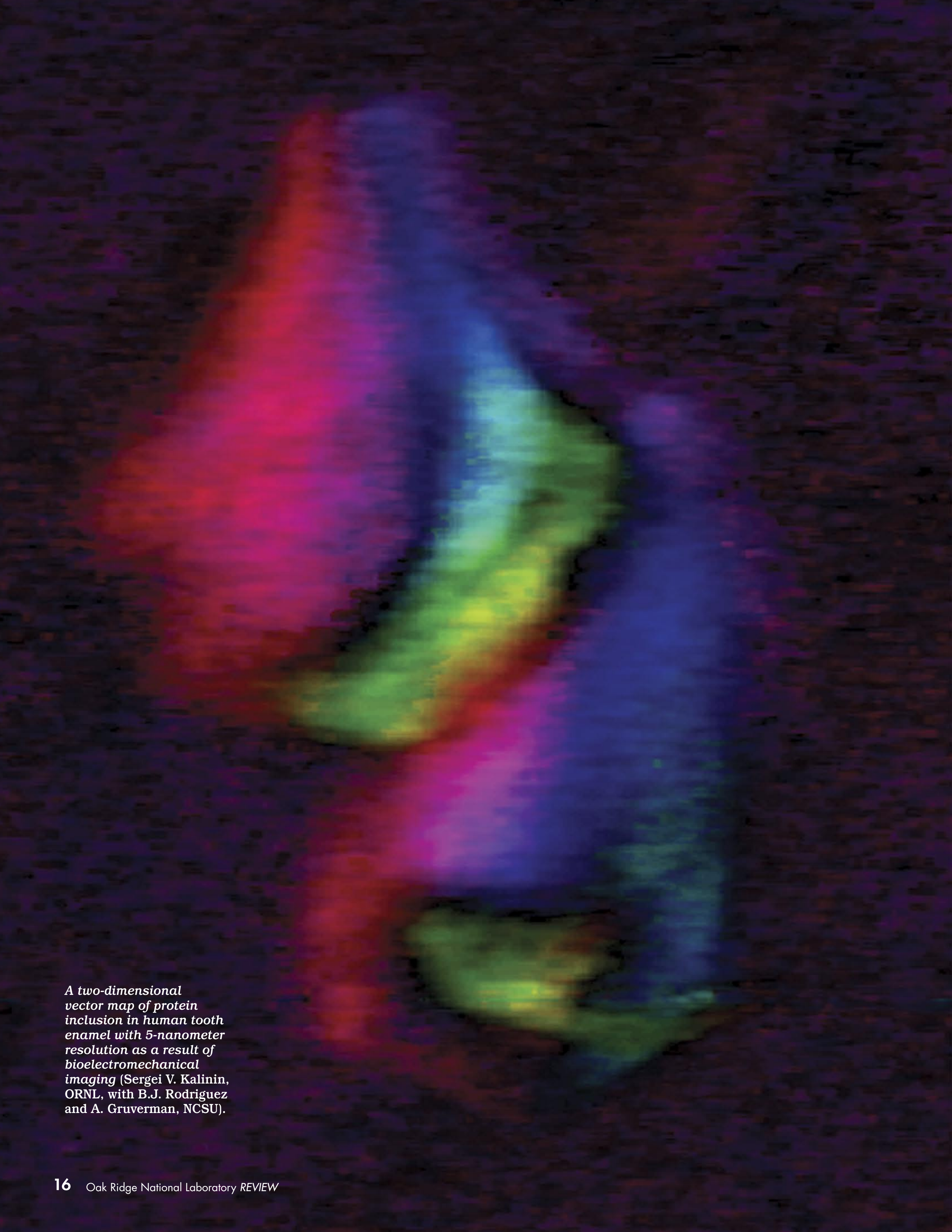
This quest has led Young, other ORNL researchers, and researchers throughout the world to collider experiments, wherein atomic nuclei were smashed from 1986 to 1996 at the CERN lab near Geneva, Switzerland, to incredibly high-energy experiments since 1989 at Brookhaven National Laboratory's Relativistic Heavy Ion Collider.

In Oak Ridge, the pathways of the universe are being explored by two Tennesseans whose Wigner fellowships led them home. Ⓡ



"The key words in his pitch were 'permanent job after two years.' "

Glenn Young



A two-dimensional vector map of protein inclusion in human tooth enamel with 5-nanometer resolution as a result of bioelectromechanical imaging (Sergei V. Kalinin, ORNL, with B.J. Rodriguez and A. Gruverman, NCSU).

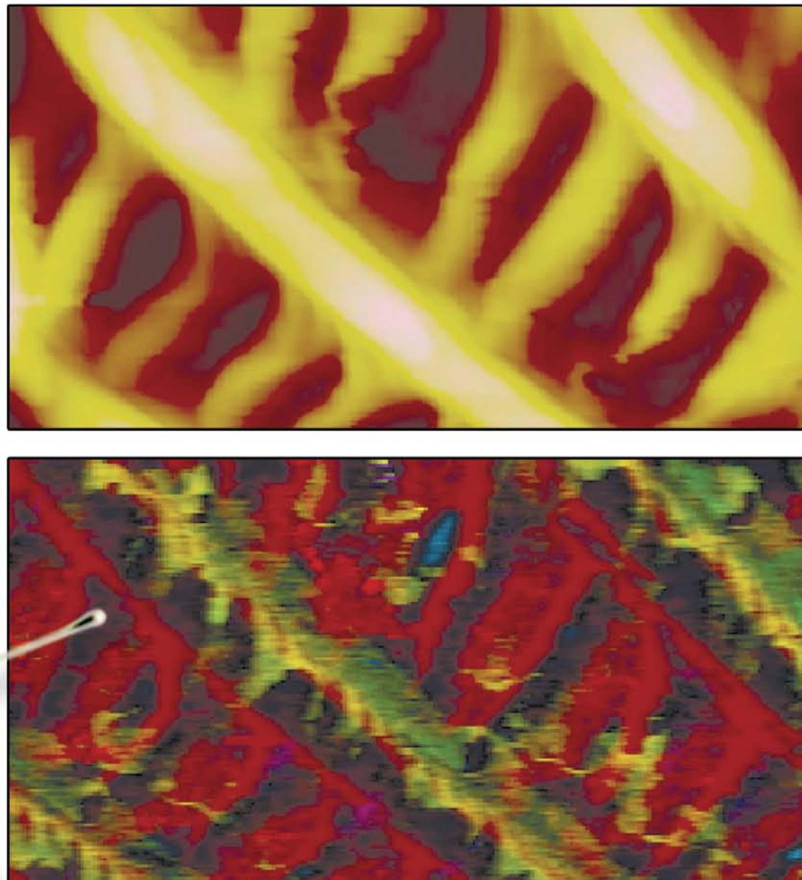
Finding the Next Small Thing

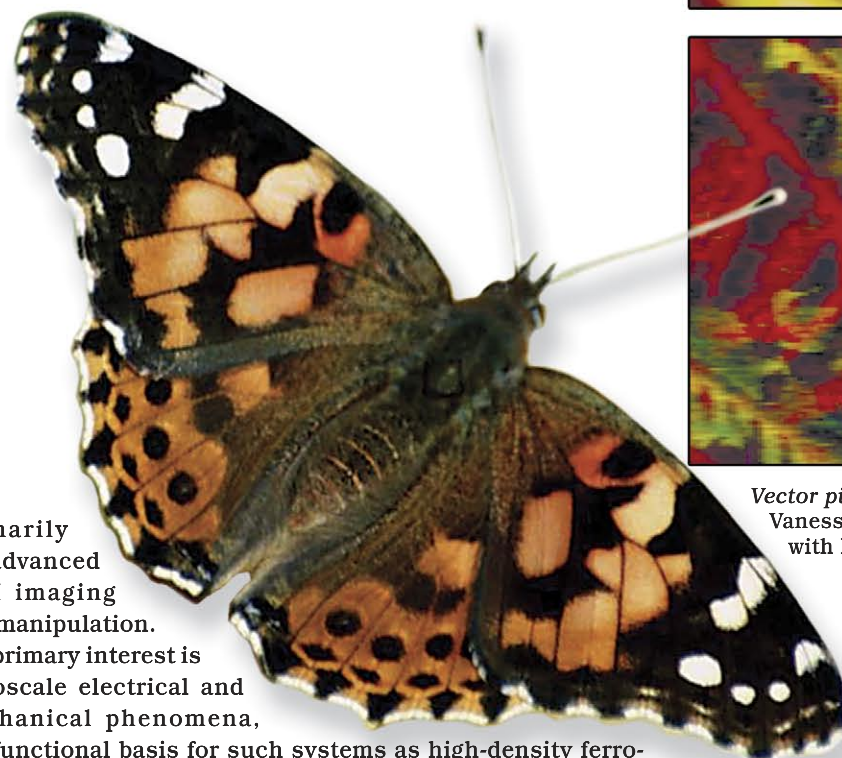
Former and current Wigner fellows are developing technologies for imaging, characterizing, and fabricating nanostructures.

ORNL "nanoscopes" are among the tools that may help researchers construct materials as elastic and durable as a butterfly's wing.

Sergei Kalinin, a former Wigner fellow (2001-2003) in ORNL's Condensed Matter Sciences Division, has pioneered several advanced scanning probe microscopes (SPM) for imaging transport and electromechanical phenomena on length scales as small as 10 nanometers (nm). To get a sense of scale, split a hair evenly into 50,000 strands. Each strand would be 1 nm wide.

Kalinin, a Russian with degrees from Moscow State University and a Ph.D. degree in materials science from the University of Pennsylvania, has authored more than 50 papers, primarily on advanced SPM imaging and manipulation. His primary interest is nanoscale electrical and mechanical phenomena, the functional basis for such systems as high-density ferroelectric non-volatile memories, micro-electrical-mechanical systems, and signal transduction from nerves to muscles in biological systems.





Vector piezoresponse force microscopy of the wing of a Vanessa Virginiensis *butterfly* (Sergei V. Kalinin, ORNL, with B.J. Rodriguez and A. Gruverman, NCSU).

Recently, Kalinin and Alexei Gruverman, a research professor at North Carolina State University, pioneered electromechanical imaging of biological systems. They were able to visualize the spiral shape of a single collagen fibril in human tooth enamel with 5-nm resolution—that is, on the level of a single molecule. Some 200 years later this approach repeats Italian anatomist Luigi Galvani's experiment on a length scale a million times smaller. Galvani's research showed that dead frog muscles would twitch when struck by an electrical spark.

Kalinin and Gruyerman achieved similar resolution using atomic force acoustic microscopy, which employs tiny blasts of sound to probe surface and subsurface structures of delicate biological materials, as exemplified by the wing of a *Vanessa Virginiensis* (American Lady) butterfly. Their early results provide clues to the complex structure underlying the elasticity and relative durability of the splendidly functional butterfly wing. Combination of acoustic and piezoresponse force microscopies may help scientists relate structure and local properties of a biological system to its functions.

In addition to electromechanical SPM, Kalinin has developed scanning impedance microscopy, in which alternating current is applied across the sample and probe tip, to provide information on frequency-dependent transport in carbon nanotubes and oxide nanowires—crucial information for developing nanoelectronic and molecular devices and sensors. For his development of this technique, Kalinin received the Ross Coffin Purdy Award of the American Ceramic Society.

"Scanning probe microscopy provides the key to understanding electrical, electromechanical, and structural phenomena on the nanoscale," Kalinin says. "I find it challenging to interpret the science behind each SPM image and to make SPM a quantitative tool for probing material properties on nanometer and, ultimately, atomic scales."

Nanomagnetic Materials

The next class of electronic devices will likely combine light-emitting, electron-conducting, and magnetic materials on a single silicon chip, providing multipurpose functionality. These devices will consume remarkably little power because bits of information will be based not on on-off (1 or 0) switches but rather on up-and-down electron spins. If "nanodots" of special materials (e.g., gallium manganese arsenide) could be magnetic at room temperature, devices could be built that would greatly improve battlefield surveillance, urban intelligence gathering, and detection of biological and chemical warfare agents.

Envisioned palm-sized technologies that exploit electron spin as well as electron charge are called spintronic devices. Such devices could outpace today's supercomputers in factoring any number down to its primes to help security agencies rapidly break the encrypted codes of hostile nations and terrorist cells.

At ORNL a leading expert on nanomagnetism and spin-dependent transport in nanostructured materials who could help design next-generation electronic devices is Jian Shen, a Wigner fellow from 1998 to 2000 who received the Presidential Early Career Award in Science and Technology in 2004. He is currently project leader of nanomagnetism and spin-dependent transport research in Condensed Matter Sciences Division. Shen has also been named a research theme leader of the Department of Energy's Center for Nanophase Materials Sciences at ORNL.

Shen and his colleagues have developed novel methods for growing artificially structured materials layer-by-layer, wire-by-wire, and dot-by-dot. The physical properties of these nanostructures can be tuned "beyond nature" by controlling the size, shape, and density of each individual nanostructure.

For example, high-density magnetic data storage devices must have nanometer-sized arrays of magnetic nanodots. Because they are so small, these nanodots usually become magnetic only at very low temperatures.

"We were able to tune the interaction between the nanodots to obtain ferromagnetism well above room temperature," Shen says. "We have also done similar tuning in magnetic semiconductors for spintronic applications."

The son of two chemists who work at the Chinese Academy of Sciences, from which he earned an M.Sc. degree in surface science, Shen obtained a Ph.D. degree in nanomagnetism at the Max-Planck Institut in Germany. At ORNL he is gaining an international reputation for his understanding of the effect of spatial confinement on magnetism and other complex behavior in nanostructured materials.

World Record

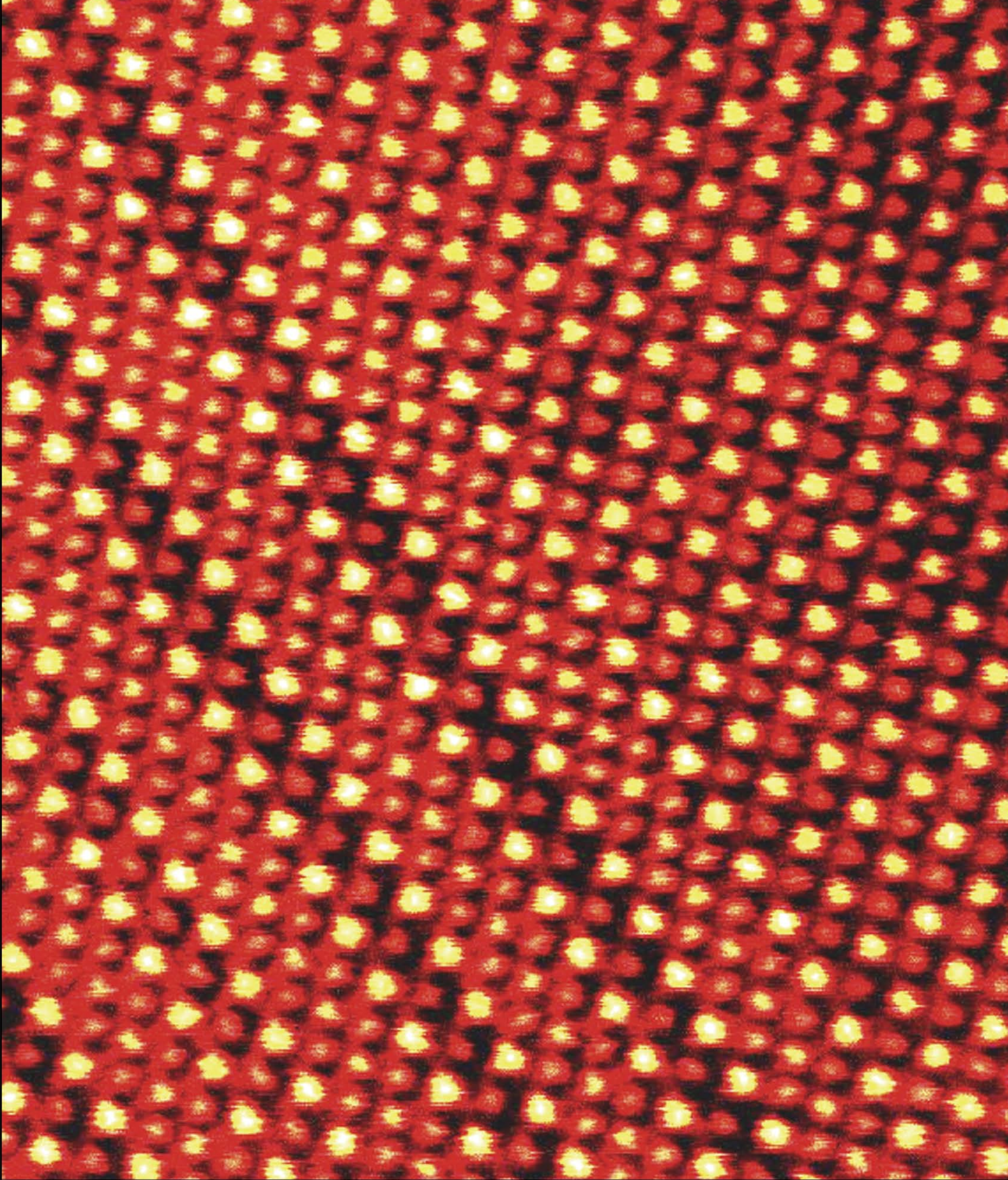
In 2004 Maria Varela achieved a world record at ORNL while performing research as a Wigner fellow. Varela made the first spectroscopic identification of a single atom when she detected a lanthanum atom introduced as an isolated impurity in a calcium titanate ($CaTiO_3$) matrix.

She imaged the lone lanthanum atom using a Z-contrast scanning transmission electron microscope (STEM). (A similar STEM achieved another ORNL world record, also in 2004, of 0.6 angstrom resolution by visualizing lanthanum atoms between silicon nitride grains.) Varela obtained additional information about the isolated lanthanum atom embedded in the solid $CaTiO_3$ matrix by using electron energy loss spectroscopy.

"The red spectrum in the electron energy loss spectra revealed the presence of a single lanthanum atom within a column of calcium atoms," she says. "We were the first to get a spectroscopic signal from an impurity atom in a solid.

"In East Tennessee, for the same amount of money as I spent on a studio apartment in Berkeley, I can rent an apartment by the lake and have a boat."

Maria Varela with her golden retriever, Chloe, and mixed-breed, Mikey.



Z-contrast image of an interface between a superconducting oxide and a ferromagnetic colossal magnetoresistant oxide. These heterostructures studied in the electron microscope by Maria Varela are potentially interesting for building a spintronic device.

"We used an electron beam to probe the lanthanum atom, exciting its electrons so they jumped to different energy levels. In this way we learned how this atom is bonded to other atoms and how it interacts chemically with its environment. The ultimate experiment in EELS is to identify a single atom by measuring how much energy was lost from the electron beam probing the atom."

Varela published a paper on the world record event in spectroscopy in the January 2004 issue of *Physical Review Letters*. The paper was one of 15 she has published since moving from Madrid, Spain, to Oak Ridge. In 2004 Steve Pennycook hired her as a staff scientist in his Electron Microscopy Group.

She has been conducting research on both superconductors and manganites, which exhibit colossal magnetoresistance. "When you put these magnetic oxides in a magnetic field," she explains, "their resistance to the flow of electricity might decrease up to a million times. They might someday be used in magnetic sensors or read heads in computer hard drives if scientists can better understand why these complicated materials behave the way they do."

Unusual Properties

In 2006 ORNL will become the world's foremost center for neutron sciences when the Spallation Neutron Source (SNS) goes into operation in conjunction with the upgraded High Flux Isotope Reactor (HFIR). Much of the research at SNS involving neutron scattering will contribute to the understanding of nanomaterials. The Department of Energy's new $65 million Center for Nanophase Materials Sciences, the agency's first, is co-located with SNS.

Mark Lumsden, a native of Canada and former Wigner fellow (1999-2001), is a staff scientist in ORNL's Center for Neutron Scattering. He co-developed the HB3 triple-axis spectrometer at the HFIR. He also helped write a modern data-acquisition software system for controlling neutron scattering instruments, called Spectrometer Instrument Control Environment. He will conduct research at the SNS.

Lumsden performed neutron scattering research to shed light on the previously unknown magnetic properties of potassium vanadate. "This vanadate is particularly interesting because its bulk properties are so unusual," he says. "In particular, when a magnetic field was applied along a certain direction, the magnetic response of this material—that is, its magnetization—showed an unexpected feature. Using neutron scattering at HFIR, we inferred that these unusual properties resulted from a competition between several magnetic interactions."

Nano Sensors

Ming Su was recruited to Oak Ridge to boost research programs in nanosensors and nanobiology. A Wigner fellow since August 2004, Su has been working with Thomas Thundat, leader of the Nanoscale Science and Devices Group in ORNL's Life Sciences Division.

At Northwestern University, Su worked on a doctoral project in which he devised tiny gas sensors from tin oxide, the material found in smoke detectors and carbon monoxide (CO) detectors in people's homes. He obtained several patents on tin oxide sensors that he miniaturized using the "dip pen nanolithography" (DPN) technique. He reported on this development in *Applied Physics Letters* and *Journal of the American Chemical Society*.

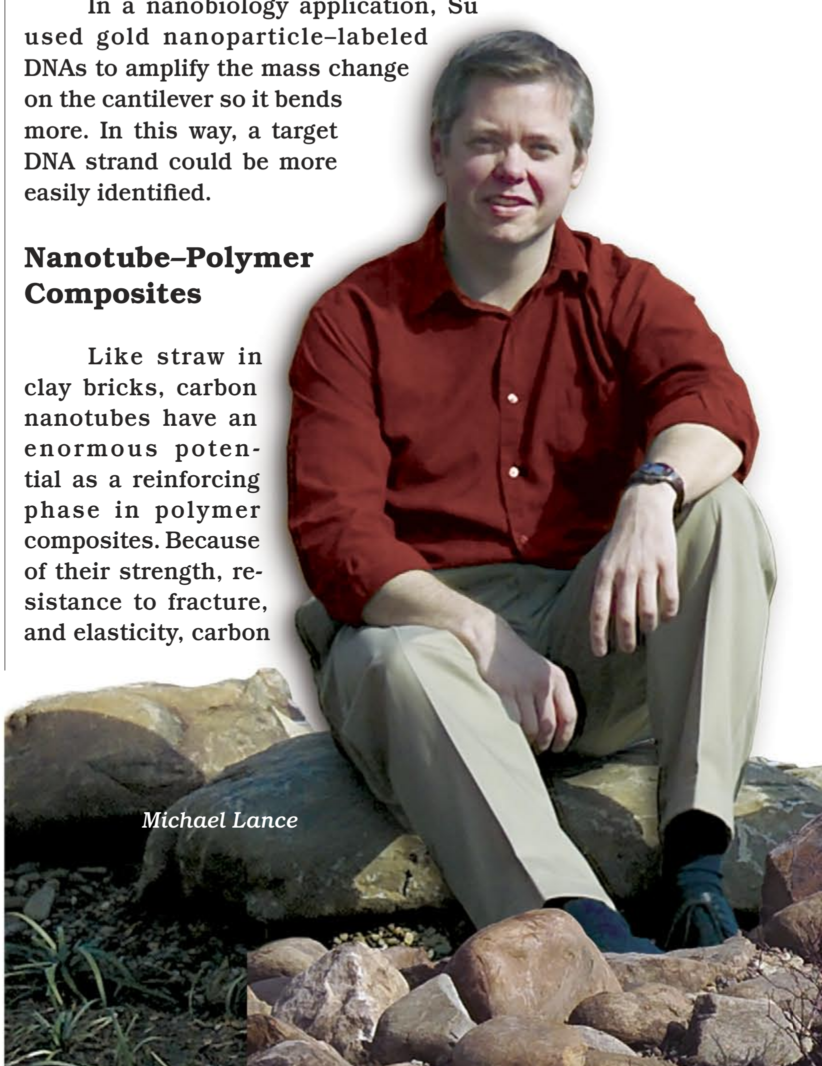
Su has invented a method of producing a nano-sized solid by writing on a surface with a liquid precursor ink. The precursor ink contains tin chloride, a metal salt, and a surfactant similar to a constituent of cosmetic creams. If the solid is a sensing material (i.e., tin oxide), the composition and sensitivity can be modified easily by doping the material with different metal ions. For instance, doping tin oxide with platinum makes it more sensitive to hydrogen and CO. When the doped oxide is exposed to these substances, its electrical resistance drops.

Su has demonstrated that DPN can modify coatings on the microcantilever sensors invented by Thundat. "DPN will make it easier to coat each microcantilever in a large array of these tiny 'diving boards' with many different nano-spots, creating an electronic nose," Su explains. "This sensor array can detect and identify different gases in the air."

In a nanobiology application, Su used gold nanoparticle–labeled DNAs to amplify the mass change on the cantilever so it bends more. In this way, a target DNA strand could be more easily identified.

Nanotube–Polymer Composites

Like straw in clay bricks, carbon nanotubes have an enormous potential as a reinforcing phase in polymer composites. Because of their strength, resistance to fracture, and elasticity, carbon



Michael Lance

nanotubes used to reinforce polymers can give the composites better mechanical properties than those of current carbon-fiber–reinforced composites. In addition, the unique electrical, thermal, and optical properties of carbon nanotubes provide polymer composites with multiple functionalities, permitting automatic alteration of their properties, depending on the environmental conditions.

Many issues remain before researchers can achieve the predicted mechanical property improvements for nanotube-polymer composites. One of many possible applications of these composites is the storage of electrical energy or hydrogen. One challenge is that the orientation of the nanotubes can radically affect the composite's properties.

In work conducted with Ilia Ivanov and Dave Geohegan, former Wigner Fellow Michael Lance and Chun-Hway Hsueh developed a computer model to predict how carbon nanotubes can reorient while under an applied stress.

"If you had a bunch of cocktail wieners in a vat of mashed potatoes and you squished the mashed potatoes, the cocktail wieners would rotate till they pointed perpendicular to the direction of compression," Lance explains. "We predicted that stiff nanotubes would act in a similar way in a compliant polymer matrix."

The new model will help researchers determine how the properties of nanotube composites change under load and suggest new ways to orient nanotubes. The research will be published in the April 2005 issue of the *Journal of Materials Research*.

Nanoparticles, Antibodies, and Bacteria

Adam Rondinone, a Wigner fellow from 2001 to 2003, has been involved in nanoscience and neutron science projects since he was a doctoral student at Georgia Tech. "I studied magnetic nanoparticles using neutron scattering at HFIR for my Ph.D. thesis research," he says.

Now a staff researcher in ORNL's Chemical Sciences Division, Rondinone is leading the development of a radioactive nanoparticle that can be attached to an antibody, potentially for the treatment of non-Hodgkins lymphoma, a type of cancer.

The nanoparticle, which will be linked to an antibody that targets lymph node tumors, can withstand various chemical environments in the body without degrading. Steve Kennel and Saed Mirzadeh of the Life Sciences Division are working with Rondinone on attaching the nanoparticles to a special antibody, a project funded internally by ORNL's Laboratory Directed Research and Development Program.

The current treatment for non-Hodgkins lymphoma approved by the Food and Drug Administration (FDA) uses an organic chelator that holds a radioactive metal, a beta emitter called yttrium-90, which can escape to the bone and destroy its marrow. The serious potential side effect limits the allowable dose of the radioactive yttrium.

"We think our approach of making a metal oxide nanoparticle with mostly natural, nonradioactive yttrium oxide and only a little radioactive yttrium-90 is safer," Rondinone says. "Encasing the radioactive yttrium metal in an yttrium oxide nanoparticle will prevent the metal from escaping because it is confined in a ceramic particle, thus eliminating the serious side effect. Our nanoparticle will not dissolve and will eventually be flushed from the body. We believe our treatment for lymphoma and other non-solid tumors could be more effective than the current approach."

Rondinone also works with Tommy Phelps in ORNL's Environmental Sciences Division on "training" certain bacteria to churn out magnetic nanoparticles of a specific size. These magnetite-synthesizing bacteria discovered by Phelps persistently grow nanoparticles measuring 40 to 50 nm. The researchers seek to alter the chemical environment of these bacteria so that they grow smaller magnetic nanoparticles of a desired size, say, for computer memories.

Working at levels almost beyond the imagination, ORNL researchers are embarking upon the discovery of "the next small thing." Ⓡ

Adam Rondinone

The Path of Least Resistance

Four past and present Wigner fellows have investigated high-temperature superconducting materials.

Eliot Specht, a researcher in the X-ray Research & Applications Group of ORNL's Metals and Ceramics Division, knows a little about a lot of resistance and a lot about electrical materials with very little resistance.

The son of two social workers, Specht grew up in Berkeley, California, a center of political radicalism in the 1960s. He was in elementary school when Governor Ronald Reagan sent the National Guard to restore order to the University of California's Berkeley campus.

Specht encountered little resistance to his passionate interest in science, however. His high-school physics teacher convinced him that he "could be a physicist and still be cool."

Since becoming a Wigner fellow in 1987, Specht has used X rays to study high-temperature superconductors, which offer almost zero resistance to the flow of electricity. These superconductors include materials partly developed at ORNL that will likely be used in high-temperature superconducting wires and cables expected to become commercial this decade.

Specht obtained a B.S. degree in physics from Berkeley and a Ph.D. degree in physics from the Massachusetts Institute of Technology. His Ph.D. thesis research consisted of experiments in which X rays were scattered from thin films to study their structural changes during melting. He performed these studies at synchrotron X-ray facilities at Stanford University and Brookhaven National Laboratory. ORNL's Cullie Sparks, who at the time was conducting experiments at the Brookhaven synchrotron, encouraged Specht to apply for a Wigner Fellowship.

"As a Wigner Fellow, I studied superconductivity and X-ray scattering from surfaces," Specht says.

In the early 1990s ORNL researchers developed the RABiTS™ (rolling-assisted biaxially textured substrates) technique for making substrates for high-temperature superconductors. Because tapes made from nickel alloys on which thin films were deposited varied in composition and structure, Specht and other researchers learned for the first time how to characterize RABiTS tapes.

Specht developed two new X-ray scattering instruments to assess the quality of RABiTS superconductors. One instrument measures the crystal orientation in buffer layers along long tapes. The other monitors the growth of films in situ after precursor material is deposited on the nickel alloy substrate.

"These measurements are important," Specht says. "They show whether the proper crystal orientation is in place for transferring the texture from the nickel alloy substrate through the buffer layers to the superconducting oxide layer on top." The top layer is usually yttrium-barium-copper oxide, or YBCO. Specht's work set the standard for an emerging field of study.

Critical Concept

John Budai has also been involved in developing new experimental, X-ray synchrotron techniques since becoming a Wigner fellow in 1984. Budai likewise has applied these techniques to various materials, including oxide films in high-temperature superconductors. While examining YBCO films grown on silver foils in 1990, he discovered they were aligned in particular crystal orientations with respect to the metal. Budai developed an explanation for this alignment and described how superconductivity could be significantly enhanced by growing films on roll-textured metal foils. His work helped motivate the development of "textured templates," the concept behind RABiTS research.

During his 20-year career at ORNL, Budai has also used X- rays to study quasicrystals, ion-implanted nanocrystals, and mesoscale microstructures. "I now use microdiffraction to make three-dimensional movies of grain growth in polycrystalline aluminum," he says.

Eliot Specht

A native of Burlington, Vermont, Budai majored in physics and math at Dartmouth College and earned his Ph.D. in physics at Cornell University, where he helped build one of the first instruments at the CHESS synchrotron facility. There he met ORNL's Ben Larson and Cullie Sparks, who were using CHESS for their research. They told Budai about the Wigner Fellowship.

After a postdoctoral stint at Bell Labs, Budai accepted a Wigner position with Larson in ORNL's Solid State Division. "Over the years, I've been involved in developing X-ray techniques at each new-generation synchrotron source," Budai says, listing facilities at Cornell and Stanford universities and then Brookhaven and Argonne national laboratories. Recently, he has been involved in developing synchrotron X-ray microdiffraction techniques at Argonne's Advanced Photon Source for "mesoscale" materials studies. Budai recently used X-ray microdiffraction to revisit his previous studies of superconducting materials.

Magnetic Fluctuations

Thomas Maier has joined the staff of ORNL's Computer Science and Mathematics Division (CSMD) after completing a very productive two years as a Wigner fellow. He submitted at least a half dozen scientific papers. He wrote a 50-page review of a computational method of simulating a system of strongly interacting electrons, including those in high-temperature superconducting materials. His review will be published in July 2005 in the *Review of Modern Physics*.

Maier has been enjoying the opportunity to use the Cray X1, a high-performance computer at ORNL, in his search for a mechanism to explain how high-temperature superconductivity works. With this powerful tool he showed in a systematic study that the widely accepted two-dimensional Hubbard model is able to describe high-temperature superconductivity.

Maier earned all his degrees, including his Ph.D. in physics in 2001, at the University of Regensburg in his hometown in Germany. His doctoral thesis about correlations of interacting electrons netted him the Röntgen Prize for young scientists.

He came to ORNL as a Wigner Fellow in March 2003 following two years of postdoctoral computational condensed matter research with Professor Mark Jarrell in the University of Cincinnati's Department of Physics. Maier's work there on simulations of high-temperature superconductors resulted in 10 first-author publications in top physics journals.

Maier now works with Thomas Schulthess, a friend and colleague of Professor Jarrell and a researcher in CSMD's Computational Materials Sciences Group. The two approach high-temperature superconductivity from different directions. They hope that together they can arrive at a more complete picture of this phenomenon.

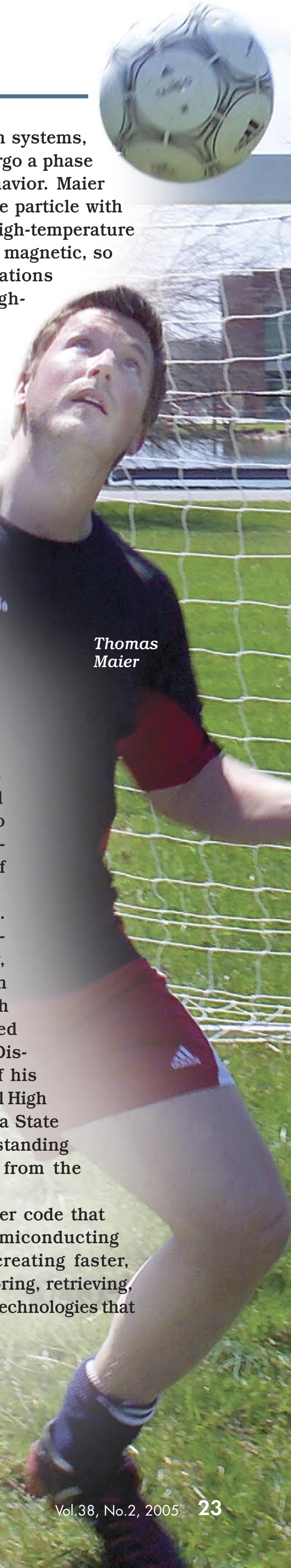
Maier takes a many-body approach in which he describes 10^{23} electrons in terms of quantum mechanics, such as the probability that any particular electron is in a certain position for a certain time. As superconductors are chilled to low enough temperatures, their electron systems, which have been disordered, "undergo a phase change" and exhibit collective behavior. Maier views each electron both as a single particle with a charge and spin and as a wave. High-temperature superconductors are close to being magnetic, so Maier thinks that magnetic fluctuations are the keys to understanding high-temperature superconductivity.

Giant Proximity Effect

Gonzalo Alvarez, a current Wigner fellow, and his Ph.D. thesis advisor, Elbio Dagotto, recently simulated on the computer the "giant proximity effect" where a high-temperature superconductor placed close to a normal material makes the normal material superconducting. "Our prediction inspired an important experiment that demonstrated the existence of this effect," Alvarez says. Ivan Bozovic performed this experiment at Brookhaven National Laboratory, and Alvarez and Dagotto published an article on the experiment in the December 2004 issue of *Physics World*.

Alvarez, who has B.S. and M.S. degrees in physics from the University of Montevideo in Uruguay, completed his doctoral research on magnetic semiconductors with Professor Dagotto, recently named an ORNL-University of Tennessee Distinguished Scientist. As a result of his thesis work in physics at the National High Magnetic Field Laboratory at Florida State University, Alvarez received an Outstanding Dissertation in Magnetism Award from the American Physical Society.

Alvarez has written a computer code that allows simulation of magnetic, semiconducting materials that may be useful in creating faster, smaller, and cheaper devices for storing, retrieving, and processing information—future technologies that may prove irresistible. Ⓡ



Thomas Maier

PROFILE

Paul Gilman:

Oak Ridge Center for Advanced Studies

"What keeps you awake at night?" is a question Paul Gilman often asks federal decision makers. For the Assistant Secretary for Water and Science at the Department of the Interior, the answer is "Water." If the issue requires scientific and technical expertise, as well as input from economists and policy analysts, Gilman may suggest this concern as a candidate topic for consideration by the new Oak Ridge Center for Advanced Studies at ORNL, of which he is the first director. Gilman says he would like ORCAS to be perceived as a "do tank," not a "think tank."

Before coming to Oak Ridge, Gilman was the science advisor for the U.S. Environmental Protection Agency. Earlier, he worked at the U.S. Office of Management and Budget, where he had oversight responsibilities for the Department of Energy and all other science agencies, and at DOE, where he advised the Secretary of Energy on scientific and technical matters. He also served as an External Member of DOE's Laboratory Operations Board.

Q. What did you do on the National Research Council?

I worked at NRC from 1993 to 1998. It was a great place for me to recharge my technical batteries because it gave me broad experience and exposure to many different controversial topics. I helped bring in a broad range of experts to talk about a topic. These experts might be economists, social scientists, or physicists. Some of the issues we worked on were nuclear waste disposal, the use of DNA-based technology in forensic science, and the use of genetically modified organisms in agriculture.

Q. Which of your accomplishments at the EPA are you particularly proud of?

The increased use of science in EPA's regional offices, where most of EPA's technical decisions are made; a new program called computational toxicology, to better understand the human health consequences of compounds in the environment; and the initiation of the Global Earth Observation System, which will enable the integration of data from tidal gauges, water stations, and measurement instruments aboard satellites to answer questions such as: "Is the sea level rising?"

Q. Why did you leave EPA to become ORCAS director?

I saw it as a chance to work at what is not a think tank but a "do" tank. I became interested in ORCAS because I knew enough about DOE national labs and Oak Ridge and the tremendous resources here. The emerging emphasis on computation and the revitalized focus on user facilities made ORNL the kind of place where the raw material is good. I have long known Lee Riedinger, Bill Madia, and Jeff Wadsworth and have a great deal of respect for their abilities. The universities view ORCAS as an international center and a regional enterprise. They want ORCAS to focus on any issue with a significant scientific and technical challenge. At ORCAS, the very best from the basic research side will be brought to bear on issues or problems that federal, state, or local policymakers have. We want to bring scientists, engineers, policy analysts, and policy makers to the table to address important issues.

Q. How will ORCAS operate? What is the ORCAS model?

We will identify the critical gaps in our knowledge; catalyze research, analysis, or computation to fill those gaps; and then feed information back into the policy debate or decision-making process. That's what makes ORCAS different from your average think tank. It doesn't mean we are funding the research; instead, we are calling attention to the gaps so a university or lab researcher might go in that direction. If we give proposed research a high enough profile, a program person at DOE or EPA might say, "This is research that should be funded." We want to keep policy people under the same tent and have them understand and interpret the researchers' data.

Q. How will ORCAS work in its new building?

The thinking always has been that ORCAS will be largely a virtual organization and not have its own large faculty. We will put a versatile, interdisciplinary team together. We will identify an issue and bring in the very best people from wherever they are, not just at the core universities and ORNL, to address that issue. As the topics change, the people involved will change. This building was constructed with very good electronic communications capabilities, to enable distance learning. It has a lecture hall that is excellent for videoconferencing. We

Starting in 1998, Gilman gained research management experience in the private sector for three years by helping Craig Venter create and manage Celera Genomics, which sequenced the human genome. From 1993 to 1998 he was the executive director of the Life Sciences and Agriculture divisions of the National Research Council, the operating arm of the National Academies of Sciences and Engineering.

From 1985 to 1991 he served as chief of staff for Senator Pete Domenici, and prior to that, he worked on the Senate Energy R&D Subcommittee, which has jurisdiction over DOE research programs. He convinced many senators to support Charles DeLisi's concept of a human genome project and helped DOE receive appropriations for human genome research.

A native of Connecticut, Gilman attended Kenyon College and received his A.B. M. A., and Ph.D. degrees in ecology and evolutionary biology from Johns Hopkins University. His plan was to become a scientist, but in 1978 he was diverted to Capitol Hill after winning an American Association for the Advancement of Science (AAAS) Congressional Science and Engineering Fellowship.

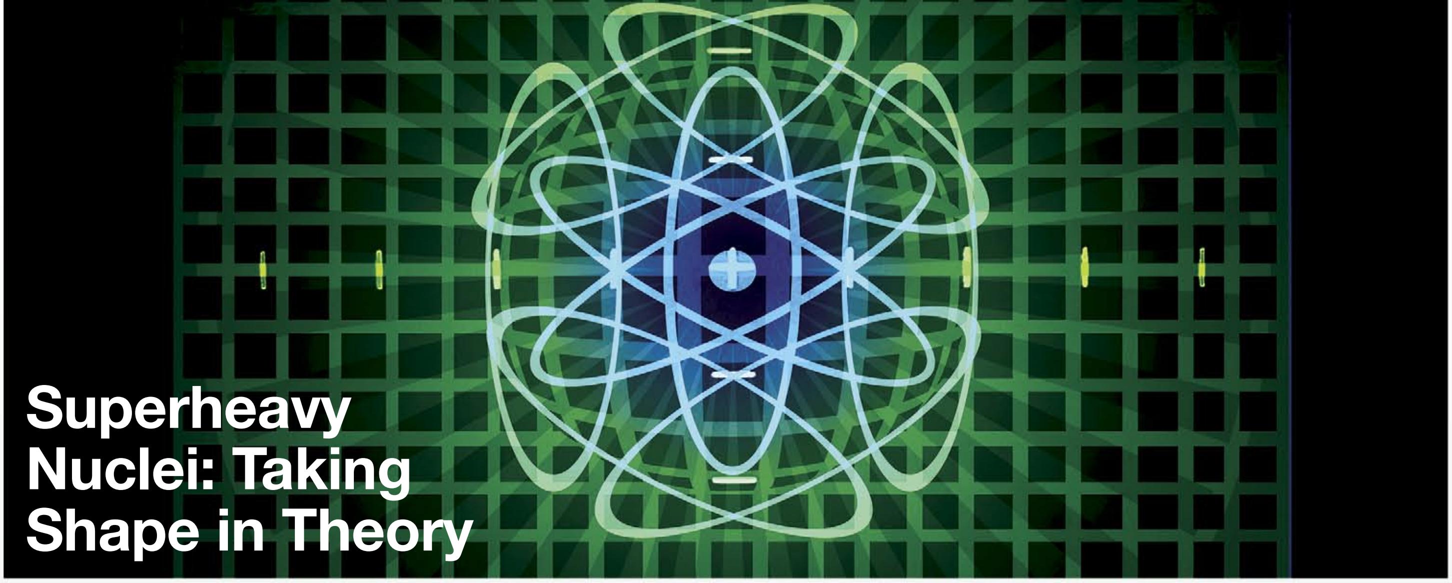
can bring people here, both electronically and physically, and send people here "there," wherever "there" might be. In the past, we worried whether a member of Congress would be able to attend our meeting because of a snowstorm or a need to vote on an important issue that day. Now we can have that policymaker "live" in our room. It's just that this person and our group will be sitting in front of cameras.

Q. What types of issues might ORCAS address?

Our program committee has already looked at a couple issues. ORCAS isn't just about energy or the environment or national security. We are concerned about any issue with substantial science and engineering content. For example, the core universities and ORNL are interested in the biomedical applications of nanotechnology. Substantive technical issues associated with nanotechnology must be understood before the social, legal, and ethical issues are addressed. Because of the concern that humans might inhale carbon nanotubes, we have to determine the dose of nanoparticles that might cause a cellular response potentially threatening to human health. Before we can talk about the social and ethical implications, we first have to understand the physical consequences. In the area of climate change, we might look at the science needed to translate the results of the global models into predictions about the human health consequences in the Southeast. Will the Southeast have more mosquito-borne infectious diseases if the regional climate is warmer and wetter? A third possible issue is housing. The U.S. government owns the most mobile homes because of federally guaranteed mortgages. Many of these homes have been abandoned because occupants can't pay the energy bills or believe these homes are unsafe. This could be an issue for energy technology, environmental health, and social policy experts.

Q. What will the final product be?

I am very hopeful that the final product won't be just a report. I'm hopeful that the final product will be the world becoming a different place because of the work that's done here . . . that the direction of research changed at some lab or a state transportation division made a decision affected by ORCAS. If we don't help the program manager from a federal department who tells us what keeps him awake at night, we will have failed from the start. ®



Superheavy Nuclei: Taking Shape in Theory

ORNL and UT researchers help predict the structure and stability of superheavy nuclei.

Advanced computational methods and supporting experiments, including work performed at ORNL, are giving scientists a better understanding of the nature and stability of superheavy nuclei and the heaviest elements that lie beyond the borders of the periodic table.

The Feb. 17, 2004, issue of *Nature* magazine featured collaborative work on these cores of superheavy atoms by researchers at ORNL, the University of Tennessee, and universities in Poland and Belgium. The authors described the behavior of superheavy nuclei that are loaded almost to their limits with protons and neutrons, posing a major challenge to the physical forces that hold them together.

The research was funded by DOE's Office of Nuclear Physics in the Office of Science and the National Nuclear Security Administration.

"Predicting the stabilities of extremely heavy nuclei has been a long-term goal of nuclear scientists," says Witold Nazarewicz, a researcher in ORNL's Physics Division and UT's Department of Physics and Astronomy. "This research represents the very best we can do at predicting the structure of these species."

The paper illustrates how protons and neutrons of extremely heavy nuclei arrange into shapes that can be either oblong or flat. The shape can help determine the stability or life of the nucleus, which is, in turn, a factor in determining if the atomic species can even exist or be synthetically created.

Because of the strong electrostatic repulsion that drives protons apart, some of these superheavy nuclei may have extremely short lifetimes.

"A typical lifetime of a nucleus in the extremely heavy range is a millisecond," Nazarewicz says. However, in some cases, certain isotopes may be much more stable, or long-lived. This stability may depend on the nuclear shape.

Experiments performed in Germany, Japan, and Russia have bolstered theories that the lives of nuclei become longer as certain configurations of protons and neutrons are achieved. Computationally intense theoretical modeling indicates that a significant difference in the shape of a "parent" nucleus that decays by emitting an alpha particle and the shape of its daughter isotope will hinder the rate of decay from parent to daughter.

"It takes time for a nucleus to decay from a flat, oblate shape to a well-deformed, elongated shape," Nazarewicz says. "Because these protons and neutrons must rearrange themselves, this shape change causes difficulty."

Some experiments indicate that the addition of neutrons to a nucleus can extend the life of an isotope of a superheavy element, such as the as-yet unnamed element 112, from a fraction of a second to more than 30 seconds. In terms of existence for extremely heavy nuclei, a half-minute is an eternity.

Nuclei in the particularly well-bound isotopes find arrangements that physicists regard as "magic." Such nuclei are reminiscent of noble gases—for instance, helium, argon, and neon—that, because of their closed electron shells, are so stable that they are known as inert gases.

Nuclei also can have closed shells of protons and neutrons. Lead-208 is the heaviest "doubly magic" nucleus with closed shells of 82 protons and 126 neutrons. "We do not really know what is the next doubly magic nucleus beyond lead-208," Nazarewicz says.

Theorists such as Nazarewicz and his *Nature* co-authors, the late S. Cwiok of the Warsaw University of Technology and P.-H. Heenen of the Free University of Brussels, believe that in the extremely heavy regions, the interplay of nuclear shapes and proton and neutron arrangements eventually will approach relatively stable, "near-magic" states.

"These theories are supported by large-scale, state-of-the-art calculations, but at the same time, lab experimenters are trying to understand the mechanisms of nuclear collisions," says Nazarewicz, who is scientific director of the Department of Energy's Holifield Radioactive Ion Beam Facility at ORNL. "Experiments with beams of radioactive, neutron-rich nuclei such as doubly magic tin-132 may teach us how to pump more neutrons into the nuclei of these superheavy elements."—*Bill Cabage* Ⓡ

A New Spin

Computer simulations at ORNL have motivated experiments that may give industry a new way to make next-generation electronic devices.

In 2001 three ORNL researchers and a physicist from Tulane University published a paper in *Physical Review B* that changed the direction of electronics research, potentially revolutionizing the storage and retrieval of data while meeting the growing demand for memory. As a result, the electronics industry is excitedly preparing to switch to a new type of on-off data storage device that could enable the fabrication of smaller, faster cell phones, digital cameras, palm-size computers, wireless devices, and satellite memory units.

When the ORNL-Tulane paper, "Spin-dependent Tunneling Conductance of Fe[MgO]Fe Sandwiches," was published, the electronics industry was beginning to use spin valves based on the giant magnetoresistance (GMR) effect for read heads in hard disk drives. Most new computers utilize GMR read heads for storing data.

The electronics industry is shifting its interest, however, from GMR devices to ones based on tunneling magnetoresistance (TMR) for read heads and magnetic random access memory (mRAM). In magnetic memory, data are represented by electron spins instead of electron charges. Such data would not have to be refreshed, eliminating the need for slow rebooting of computers and greatly reducing power consumption. An added benefit would be that data stored in magnetic memory in satellites and elsewhere in outer space cannot be damaged by radiation.

Thomas Schulthess and Xiaoguang Zhang, both in the Computational Materials Sciences Group in ORNL's Computer Science and Mathematics Division, coauthored the 2001 paper with lead writer, Bill Butler, a theorist then at ORNL and now at the University of Alabama, and J. M. MacLaren of Tulane University. Their paper, based on first-principles calculations using ORNL's IBM SP2 supercomputer, suggested that research on experimental TMR devices had been directed at the wrong material.

"Researchers were focusing on aluminum oxide as the insulating barrier layer between iron layers in a thin-film sandwich only 50 nanometers thick," says Zhang. "We explained why they should try looking at magnesium oxide as the barrier."

The ORNL-Tulane group predicted that a device based on magnesium oxide (MgO) instead of aluminum oxide (Al_2O_3) would be 10 times more sensitive to magnetic data—bits of 1 and 0 stored as nanosized magnetic particles crammed together in a tiny space. A read head could then turn an extremely small magnetic signal into an electrical signal that results from changes in resistivity. In this way, stored data in ever-smaller devices can be copied to computers.

The sensitivity to the magnetic data is measured in the TMR ratio, defined as the ratio between the resistivity values with and without a magnetic field. "Our paper states that because magnesium oxide, unlike aluminum oxide, is crystalline, MgO preserves the pattern by which the electron wave is spread out, boosting the TMR ratio by more than an order of magnitude," Zhang says.

The computer simulation performed at ORNL was funded by the Defense Advanced Research Projects Agency and through cooperative research and development agreements between DOE and IBM and later Seagate Technology, Inc.

In 2004 two experimental groups at IBM and the Nano-Electronics Research Institute in Japan published papers that agreed with the ORNL-Tulane prediction. The two groups measured TMR in Fe[MgO]Fe samples and found that the TMR ratio was an order of magnitude higher than that obtained in samples using Al_2O_3 as the barrier layer.

Because of these experiments, which were motivated by the ORNL-Tulane paper and which validated the accuracy of the ORNL computer simulations, companies such as Motorola and Honeywell are excited by the potential of TMR memory devices for next-generation electronic devices ranging from cell phones to satellites. Ⓡ

...and the WINNERS are...

Accomplishments of Distinction at Oak Ridge National Laboratory

ORNL Director **Jeff Wadsworth** has been elected to the ***National Academy of Engineering*** for his "research on high-temperature materials, superplasticity, and ancient steels, and for leadership in national defense and science programs."

Charles Forsberg received the ***Robert E. Wilson Award*** from the American Institute of Chemical Engineers for his exemplary work in nuclear technology.

Gerard M. Ludtka, previous winner of the Department of Energy's E. O. Lawrence Award, has been named a **fellow of the American Society of Metals International.**

Sujit Das received the Minerals, Metals, and Materials Society's 2005 Light Metals Division JOM ***Best Paper Award***.

Richard Swaja, who is on assignment to the National Institutes of Health, has been elected to the ***College of Fellows of the American Institute of Medical and Biological Engineering.***

Witold Nazarewicz, Glenn Young, and Mariappan Parans Paranthaman, have been elected ***fellows of the Institute of Physics*** in the United Kingdom.

Amit Goyal was elected a ***consulting fellow of the World Innovation Foundation***, an international, multidisciplinary consultative research group that advises nations and their governments behind the scenes. He also received a ***Department of Energy Exceptional Accomplishment Award***.

Chin-Chi (Jim) Tsai coauthored an article that won the ***Outstanding Paper Award*** from the Atomic Energy Society of Japan. The research documented in the 2003 paper, published in the *Journal of Nuclear Science and Technology*, is a collaboration of the Japan Atomic Energy Research Institute, Ibaraki University, and ORNL. Ⓡ

Jeff Wadsworth with Katy and Badger.

Next issue

As if overnight,

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